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Understanding human-elephant interactions in and around Makgadikgadi Pans National Park, Botswana

Understanding human-elephant interactions in and around Makgadikgadi Pans National Park, Botswana

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Cover photo: a male elephant crossing a veterinary fence, leaving the Makgadikgadi Pans National Park, Botswana. Photo taken by James A. Stevens.

Abstract

In Botswana, the influx of male African elephants into the Makgadikgadi Pans National Park (MPNP) has resulted in the region becoming a hotspot for human-elephant interactions, with elephants leaving the MPNP to forage on crops. I sought to gain an understanding of human-elephant interactions in the region.

None of the field characteristics studied indicated whether a field would be entered by elephants or the frequency of entry. Certain characteristics influenced the extent and value of damage. More isolated fields incurred larger areas of damage at the end of a field season and fields with a higher crop diversity resulted in larger areas of damage and a higher cost of damage. Crop-foraging events increased as the season progressed, with fewer events occurring during a full moon. Crop-foraging elephants did not adjust their group size outside the MPNP. However, the age of elephants predicted their probability of foraging on crops, with crop-foraging events predominantly involving older male elephants. Elephants showed directed movement towards, and foraged non-selectively but intensively within, fields.

Negative experiences with elephants influenced farmers' attitudes due to the occurrence of events, not the extent of damage. Farmers' value for elephants was lower if elephants had entered their field that year and if they had encountered elephants that year, while tolerance was lower if elephants had entered their field that year and decreased with increasing numbers of crop-foraging events. Compensation estimates differed between stakeholder groups with farmers' reporting the highest estimates of damage, followed by government estimates and then transect estimates, attributable to the structure of the compensation system and differing perceptions of damage.

These results highlight the importance of understanding human-wildlife interactions at the individual field level, and the need to understand attitudes of farmers beyond the direct costs of crop damage if humans are to coexist with elephants.

Dedication

Mum and Dad

You have supported and encouraged me in everything I have done and I cannot thank you enough. I look forward to showing you the beauty of Botswana!

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Author’s declaration

I declare that the work in this dissertation was carried out in accordance with the requirements of the University's *Regulations and Code of Practice for Research Degree Programmes* and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, the work is the candidate's own work. Work done in collaboration with, or with the assistance of, others, is indicated as such. Any views expressed in the dissertation are those of the author.

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Chapter 1. General introduction

1.1 Human-wildlife interactions

Interactions between people and wildlife are an emerging issue in global conservation and potentially one of the greatest threats to wildlife after climate change and habitat loss (Madden 2004; Dickman 2010). With increasing human populations, habitat loss, increasing wildlife populations and climate change causing wildlife to move into areas where they might previously have been absent, there is greater range overlap between both people and wildlife. This leads to potential increases in negative interactions between people and wildlife, and involves species as diverse as raptors in Scotland (Thirgood & Redpath 2008), jaguars *Panthera onca* in South America (Rabinowitz 2005) and orangutans *Pongo* spp. in Indonesia (Meijaard *et al.* 2011).

Wildlife can have impacts upon humans in numerous ways. These may be visible and direct, such as crop and livestock loss, damage to property or injuries and fatalities (Saberwal *et al.* 1994; Odden *et al.* 2002; Thirgood, Woodroffe & Rabinowitz 2005; Dhamorikar *et al.* 2017), or hidden and indirect, including the time, money and effort spent preventing wildlife damage, health impacts, or costs associated with access to resources or transactions (Ogra 2008; DeMotts & Hoon 2012; Barua, Bhagwat & Jadhav 2013). These negative interactions can be costly for wildlife and people. Retaliatory killing of wildlife can have dramatic effects on the populations of some species (Burbidge & Woinarski 2016; Nowell *et al.* 2016; Durant *et al.* 2017; Voigt *et al.* 2018), while altering the ranging patterns and behaviours of others (Graham *et al.* 2009a; Ladle *et al.* 2018). The extirpation of keystone species from ecosystems can negatively influence the structure of entire ecosystems (Smith, Peterson & Houston 2003).

Negative interactions between people and wildlife have historically been described using terms such as “human-wildlife conflict”, “crop-raiding” and “crop-raid”, suggesting that there is conscious antagonism between wildlife and humans (Peterson *et al.* 2010). Although these terms are not generally used to imply that animals are behaving aggressively towards people (Hill 2017a), they result in the perception that wildlife behaviour is the source of human-wildlife conflict and that humans are the victims. In recent years it has been suggested that human-wildlife conflict is better represented as human-human conflict (Marshall, White & Fischer 2007) or conservation conflict (Redpath *et al.* 2013). Separating the interactions into two components provides a better framework with which to address the situation. Interactions between humans and wildlife cause impacts, whereas it is the interactions between people with different values, beliefs and priorities that result in conflict. Consequently, instead of using terms such as “human-wildlife conflict”, “crop-raiding” or “crop-raid”, neutral descriptors such as “human-wildlife interactions”, “crop-foraging” and “crop-foraging event” respectively will be used in this thesis. This terminology is starting to appear in the literature and provides a better platform with which to address these conservation issues (Hill 2017b; Smit *et al.* 2017).

To resolve human-wildlife interactions, we need to understand both the people and the wildlife (Madden 2004). Most research has typically involved understanding the interaction from the wildlife’s perspective. The focus has been on identifying why wild animals undertake behaviours that are potentially dangerous to themselves (Ahlering *et al.* 2011; Goodrich *et al.* 2011; Elfstrom *et al.* 2014; Khorozyan *et al.* 2015) and determine patterns to these interactions at both the individual species (Wilson *et al.* 2006; Hockings *et al.* 2010; Teichman, Cristescu & Nielsen 2013) and multiple species levels, generally in a small area or region (Kolowski & Holekamp 2006; Linkie *et al.* 2007; Sangay & Vernes 2008). Many studies have also tried to identify interactions in individuals with certain characteristics, for example, whether a demographic group is disproportionately involved in interactions (Stander 1990; Odden *et al.* 2002). From the human perspective, most studies have focussed on understanding people’s perceptions of any interactions (Campbell-Smith *et al.* 2010; Vaclavikova, Vaclavik & Kostkan 2011; Suryawanshi *et al.* 2013; Boast *et al.* 2016), attitudes towards the wildlife species involved (Lindsey, du Toit & Mills 2005; Zimmermann, Walpole & Leader-Williams 2005; Rust & Marker 2013) and consequently their behaviour in response to such interactions (Marchini & Macdonald 2012; Hazzah *et al.* 2017).

Previous studies have involved large spatial or temporal scales, resulting in areas being identified that were prone to interactions at the macro scale, allowing delineation of management zones (Sitati *et al.* 2003; Treves *et al.* 2004). Comparing distinct groups of people or stakeholders identified groups of people that have different attitudes towards wildlife (Bandara & Tisdell 2003; Karlsson & Sjostrom 2007; Piedallu *et al.* 2016). However, it is now recognised that numerous factors make each interaction unique, resulting in solutions to human-wildlife interactions being location-specific (Madden 2004). What works in one location might not necessarily be effective in another. Managers and practitioners on the ground require local patterns and characteristics of interactions to be identified, and need to understand what influences attitudes within the stakeholders that are most affected by these interactions (Bath 1998; Webber *et al.* 2011).

1.2 Elephant range and population

There are three species of African elephant, two that are named species (*Loxodonta africana* and *Loxodonta cyclotis*), and genetic data suggests that the western elephants should also be a separate species (Roca *et al.* 2001; Eggert, Rasner & Woodruff 2002). For convenience, I will refer to this amalgam of species as “the” African elephant. The African elephant is found in 37 sub-Saharan African countries, and has a current population of 415,428 ± 20,111 (95% CL), with the potential for an additional 117,127 to 135,384 in areas not systematically surveyed (Blanc 2008; Thouless *et al.* 2016). It is listed as Vulnerable on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species, and a recent survey suggests that between 2007 and 2014, elephant populations decreased by an estimated 144,000, with populations decreasing at 8% per year as a result of poaching (Chase *et al.*

2016). The 2016 African elephant status report was the first one in 25 years to report a continental-scale decline in elephant numbers (Thouless *et al.* 2016). It is likely that, with 70% of the species range outside protected areas, human-wildlife interactions will increase.

The African elephant is an intelligent, social and iconic keystone species that plays a unique role in the balance of African ecosystems, providing ecological and economical value to humans (Douglas-Hamilton 1972; Moss & Poole 1983; Western 1989; Bond 1994). It was one of the first flagship species used by conservation organisations to raise awareness and action for conservation efforts (Western 1987; Verissimo, MacMillan & Smith 2011). Elephants play an essential role in ecosystems by maintaining suitable habitat for several grazing and browsing species (Western 1989).

The conservation priorities for elephants have changed over time. Initially threats to elephants involved habitat damage or loss (Caughley 1976), moving to ivory poaching (Douglas-Hamilton 1987; Caughley, Dublin & Parker 1990). Currently, the main threats to the African elephant are habitat loss and fragmentation, human-elephant interactions, poaching for meat and ivory, and negative localised impacts of elephants on their habitat (Blanc 2008; Thouless *et al.* 2016). The loss and fragmentation of habitat can be attributed to human population expansion and the resulting land conversion (Barnosky *et al.* 2012). This results in human and elephant ranges increasingly overlapping, leading to negative interactions (Kangwana 1995). Negative human-elephant interactions are starting to gain more status as an increasing threat to elephants after poaching, although the poaching crisis is still the main threat (Thouless *et al.* 2016).

1.3 Human-elephant interactions

Negative interactions have been identified in most areas where elephant and human ranges overlap (Hoare 2000a). These occasionally include injury or death of people, damage to property or competition with domestic animals for resources (Thouless 1994; Kangwana 1995). One of the main interactions is through elephants entering farmers' fields and damaging crops (Thouless 1994; Barnes 1996). These interactions cause elephants to be feared and consequently viewed as dangerous, potentially resulting in people retaliating by injuring or killing elephants (Hoare 2000a). If poaching is to be curbed and elephant populations increase, negative interactions between elephants and humans are likely to escalate and could become the main long-term threat to elephant numbers.

1.3.1 Farmers

It is often subsistence farmers that bear the impacts of crop-foraging by elephants. Although not the most common crop-foraging species, or the one that cumulatively causes the most damage, elephants cause the most damage per crop-foraging event (Naughton-Treves 1998; Gillingham & Lee 2003). Farmers' perceptions of which animals are responsible for crop damage are accurate, with smaller bodied wildlife species such as bush pigs *Potamochoerus porcus*, vervet monkeys *Cercopithecus aethiops* and rats *Rattus* spp. causing the most damage (Gillingham & Lee 2003). However, elephants are larger and more dangerous than other species, resulting in them having a higher profile and being less readily tolerated (Hoare 2000a). Tolerance of elephants is influenced by primary land use, with people practising agriculture being less tolerant of elephants than pastoralists (Gadd 2005). Human characteristics can be used to predict people's support of conservation issues (Hill 1998). For example, women in Budongo Forest Reserve, Uganda, were more likely to express negative attitudes towards conservation than men and reported that elephants were dangerous even though they were absent from the area (Hill 1998).

1.3.2 Elephants involved in interactions

Male elephants are mainly responsible for entering fields, causing loss of crops, damage to properties and sometimes loss of life (Thouless 1994; Hoare 1999a; Mosojane 2004; Chiyo *et* *al.* 2011c; Smit *et al.* 2017). Crop-foraging by male elephants is a high-risk, high gain, strategy (Chiyo *et al.* 2011b). The high proportion of older individuals involved in such events is linked to reproduction and the associated increased energetic costs or increased risk-taking behaviour to attain peak reproductive status (Chiyo *et al.* 2011b; Chiyo, Moss & Alberts 2012). Although predominantly a male behaviour, in some areas crop-foraging is carried out by family herds, individual males and bachelor groups (Hoare 1999a).

1.3.3 Patterns of interactions

Temporal patterns of crop-foraging have been observed for both African and Asian elephants *Elephas maximus*, with most occurring towards the end of the wet season when crops are ripening (Tchamba 1996; Bhima 1998; Chiyo *et al.* 2005; Gubbi 2012). Crop-foraging by elephants mainly occurs between dusk and dawn, and elephants may avoid crop-foraging on nights with a full moon (Hillman-Smith *et al.* 1995; Sitati *et al.* 2003; Graham *et al.* 2009a; Gunn *et al.* 2014). In contrast, spatial variation of crop-foraging has shown few universal patterns, making it difficult to predict where interactions will take place. Spatial factors include increasing human population density, the increasing transformation of land to agriculture, reduced distance to rivers and daytime elephant refuges (Hoare & Du Toit 1999; Parker & Osborn 2001; Sitati *et al.* 2003). The irregular and unpredictable nature of human-elephant interactions might be a result of the behavioural ecology of individual bull elephants (Hoare 1999a).

1.3.4 Field characteristics

Few studies have investigated how the characteristics of fields might influence the frequency of crop-foraging events and the extent of damage. Factors investigated include how the area of damage varies for crop species (Sitati, Walpole & Leader-Williams 2005), whether the proportion of different crops influenced the probability and extent of damage, whether certain crops were eaten more than others, and the frequency of crop damage to different crops

(Webber *et al.* 2011; Guerbois, Chapanda & Fritz 2012; Pittiglio *et al.* 2014). While maize is often identified as the crop most vulnerable to elephant damage, most studies do not account for the availability of the crop within the field. Similarly, the type of damage is often not quantified. Crop losses result from elephants foraging on crops, with collateral damage due to elephants moving through fields and trampling crops. Just because elephants enter a field does not necessarily mean that they have foraged on certain crops. The size of fields has been linked to the probability of elephants entering, with larger fields being more vulnerable (Sitati, Walpole & Leader-Williams 2005). However, this is probably due to human guarding effort decreasing with increasing field sizes (Sitati, Walpole & Leader-Williams 2005). The risk of crop-foraging events increased with the number of crops present in a field (Sam *et al.* 2005), which was a predictor for the frequency of crop-foraging events (Barnes *et al.* 2005). Beyond that, the efficacy of mitigation strategies has been tested, but the variation in farmer effort and the difficulty of performing controlled studies mean that few studies have produced reliable results (Sitati & Walpole 2006; Graham & Ochieng 2008; King *et al.* 2017; Pozo *et al.* 2017).

1.3.5 Impacts

Although crop-foraging events are rare, the extent of damage can be potentially devastating to the farmer. In Kenya, the median proportion of damage per farm was 37.5% of crop area (Sitati, Walpole & Leader-Williams 2005), whereas in Botswana only 2.0% of a field was damaged (Songhurst & Coulson 2014). Placing a value on this damage can be difficult because crops vary in value temporally and spatially, and fields with polyculture crops vary in planting densities both within and between fields (Naughton, Rose & Treves 1999). A financial value is often not representative of the impact of the damage (Hill 2004) and farmers may overestimate the value or extent of damage (Hoffmeier-Karimi & Schulte 2014).

1.4 Managing human-elephant interactions

Studies into human-elephant interactions and their management started in the mid-1990s (Hoare 2015). Management strategies based on different studies fall into three types: biological, physical and governance (Hoare 2015).

Initially it was thought that the removal of problem elephants might provide a biological solution (Thouless & Sakwa 1995). Although a large proportion of "problem elephants" were male, there were a small number of habitual crop-foragers, whereas most elephants were occasional foragers (Chiyo *et al.* 2011c; Smit *et al.* 2017). Therefore, even if problem elephants were removed from the population there were many elephants that could take their place. So the removal of "problem elephants" was not a practical solution (Hoare 2015).

Physical strategies have included traditional deterrents such as fire, noise, torches and scarecrows, but these have had mixed success, and some put people in direct contact with elephants (Osborn & Parker 2002; Osborn & Parker 2003; Sitati & Walpole 2006; Graham & Ochieng 2008). More modern techniques have included the use of olfactory repellents such as chilli fences or chilli bricks (Osborn 2002; Hedges & Giunaryadi 2010; Pozo *et al.* 2017), and beehive fences utilising the natural avoidance of elephants to African honey bees *Apis mellifera scutellata* (King *et al.* 2009). Fencing has often been suggested as a potential barrier to keep elephants out of certain areas. This can be successful initially (Kioko *et al.* 2008; Graham *et al.* 2009b); however, with time, maintenance requirements and a lack of institutional arrangements mean that fences often fall into disrepair and become ineffectual (Hoare 2012).

Governance strategies have involved managing land use to reduce the chances of elephants encountering farmers' fields. These include allocating land for agriculture in areas where elephants are absent or far from elephant corridors (Sitati & Walpole 2006; Songhurst & Coulson 2014). In some African countries, governments pay compensation to increase tolerance to elephants as a means of managing human-elephant interactions. Compensation schemes reimburse individuals or their families for damage caused by wild animals to crops, livestock or property, and if an individual is killed or injured by a wild animal (Nyhus *et al.* 2005). However, these schemes have been largely ineffective for a variety of reasons and so the IUCN African Elephant Specialist Group advises against monetary compensation for elephant damage (Hoare 2000b).

While few studies have attempted to test many of the mitigation strategies, it is widely accepted that there is no “silver bullet” and that mitigation should come as a “package” of tools to be used together rather than in isolation (Madden 2004; Woodroffe, Thirgood & Rabinowitz 2005; Sitati & Walpole 2006; Blackwell *et al.* 2016).

1.5 Range and populations of elephants in Botswana

Botswana is a relatively small, sparsely populated African nation with a population of ≈2,000,000 (Statistics Botswana 2014). Since independence in 1966, it has achieved political stability, democratic governance and maintained strong economic growth. Botswana’s situation is regarded as a success story in comparison to many other African countries (Acemoglu, Johnson & Robinson 2001). One of the reasons for this success was the discovery of diamonds, with mining contributing 40% of Botswana’s GDP (Malema 2012). However, it is Botswana’s low volume, high value, nature-based tourism that remains its most important services export as it aims to diversify revenue sources from diamonds (World Bank 2015). Tourists from all over the world travel to Botswana for its vast wilderness areas and diversity of wildlife. As one of the few sustainable sectors, it is likely to play an important role in Botswana’s future. Therefore, coexistence between wildlife and the communities that live alongside it is crucial.

Botswana has the largest African elephant population of all the range states. The 2016 African elephant status report estimated that there were 131,626 ± 12,508 (95% CL) elephants (Thouless *et al.* 2016), while aerial surveys conducted in 2014 estimated 129,939 ± 12,501 (95% CL) (Chase *et al.* 2015). Botswana is one of the few countries where range expansion is occurring for elephants both to the west, towards Namibia, and south, with herds being sighted in the Central Kalahari Game Reserve (Thouless *et al.* 2016). In recent history Botswana's management policy has been based on non-intervention and elephant conservation in Botswana's Northern Conservation Area (NCA) has been relatively successful over the last two decades. The creation of the multinational Kavango-Zambezi Transfrontier Conservation Area (KAZA), the largest conservation area in the world, has meant that animals are no longer confined to protected areas and are able to move back into their historical range lands (KAZA TFCA 2015). However, this freedom of movement has resulted in elephants encountering subsistence farmers, commercial ranchers and communities.

1.6 Approaches to elephant conservation in Botswana

Botswana's approach to elephant management is relatively passive. There is no population control culling and hunting was banned in 2014 (Mbaiwa 2017). Botswana does have a government-managed compensation scheme whereby damage to crops or property is compensated (Hoare 2000b). Other interventions have included a joint project between the World Bank and the Government of Botswana (Northern Botswana Human Wildlife Coexistence Project) to "mitigate human-wildlife conflict through proactive prevention interventions in selected rural communities in Northern Botswana". However, independent evaluation ratings put the outcome as moderately unsatisfactory (Independent Evaluation Group Review Team 2017). Subsistence farmers primarily use traditional mitigation strategies to keep elephants out of fields. If detected in fields, wildlife officers may be called to scare elephants out depending on access to vehicles and availability. It is legal for farmers to kill elephants in their field if they are causing damage or are a threat to human life, and this does occur.

1.7 The Makgadikgadi region

The Makgadikgadi and Nxai Pans National Park is located between S19º 32’- 20º 50’ and E24º 16’- 25º 07’ in central northern Botswana. The Makgadikgadi Pans National Park (MPNP) covers an area of 3900km^2 within the 37,000km^2 Makgadikgadi basin, Botswana’s largest wetland ecosystem. Two ecological features play an important role in the Makgadikgadi basin system: rainfall and the flow of ephemeral rivers. There are two main seasons in Botswana, the wet season from October-May and the dry season from June-September, with temperatures reaching a maximum of 35.5°C in the wet season and 28.0°C in the dry season with extremes of 43.0°C down to -6.0°C (Thomas & Shaw 1991). Unseasonal rainfall is rare, with average rainfall of 450mm in the wet season.

There is limited surface water within the national park. The salt pans sit in a depression (the Kalahari basin) fed through seasonal rainfall and two ephemeral rivers. The Nata River is the most important river in the area. It flows reliably and empties into Sua Pan. However, the Boteti River on the western boundary of the national park flows out of the Okavango Delta, empties into Ntwetwe Pan and is the only permanent, natural source of water in the national park. The flow of water in the Boteti River can be sporadic, with shifts in the dynamics of water movement in the Okavango Delta affecting the reliability of flow. Historically the Boteti River was permanent, with distinct periods of flow. From January to May flow would be low, increasing from June to December. These distinct periods of flow are due to rainfall in the Angolan highlands and the Okavango Delta. In 1989 the Boteti River stopped flowing, restricting water availability to approximately 80 natural waterholes within a 23km stretch of river that were replenished by groundwater base flow (Brooks 2005). After seasonal rain, this increased to 170 sites along the riverbed. From 2008 the Botswana Department of Wildlife and National

Parks (DWNP) installed 14 artificially pumped waterholes along the western boundary of the national park to alleviate the pressure on the wildlife in the area. In 2009, the Boteti River started to flow and is once again a permanent source of water in the national park.

The return of the Boteti River has been crucial for the wildlife that rely on it for survival. The Boteti River supports several water-dependent species including zebra (*Equus quagga*), wildebeest (*Connochaetes taurinus*) and impala (*Aepyceros melampus*). Hippopotamus (*Hippopotamus amphibious*) can be found in the Boteti River, while groups of bull elephants (*Loxodonta africana*) move through the national park. The national park provides a harsh environment for wildlife and is dominated by xeric species including kudu (*Tragelaphus strepsiceros*), giraffe (*Giraffa camelopardalis*), gemsbok (*Oryx gazella*), steenbok (*Raphicerus campestris*), springbok (*Antidorcus marsupialis*) and hartebeest (*Alcelaphus buselaphus*). The dominant predator in the park is the lion (*Panthera leo*) which, with the brown hyaena (*Hyaena brunnea*), suffers high levels of persecution from the local communities (Hemson 2003; Maude 2010). Leopard (*Panthera pardus*), cheetah (*Acinonyx jubatus*), wild dog (*Lycaon pictus*) and spotted hyaena (*Crocuta crocuta*) can also be found in low numbers.

With the resurgence of the Boteti River and elephant populations expanding in the north, there has been an influx of African elephants, primarily males, into their historical rangelands (Chase 2011; DWNP 2012). This has led to many male elephants utilising the Boteti River and consequently increasing spatial overlap with the communities on the western side of the park, resulting in an increase in the number of human-elephant interactions. The MPNP is surrounded by communal land dominated by arable and cattle farming, and the region has the highest level of negative human-wildlife interactions in Botswana (Brooks & Bradley 2010). Due to the relatively recent occurrence of these interactions, there are few on-farm mitigation strategies in place as historically farmers did not have to protect their fields from elephants. Current deterrents in place involve traditional mitigation methods, for example, scarecrows or hanging cloth. Farmers normally leave their fields in the evening and return the following morning: there is no active guarding at night. Although fields are fenced with some barrier (acacia or wire fence), these are more to demarcate field boundaries than pose a barrier to elephants.

1.7.1 Study area

I chose the MPNP for my study because human-elephant interactions are a widespread and increasing problem in the region (Figure 1.1). I focussed on two communities on the western boundary of the MPNP, Khumaga and Moreomaoto with populations of 923 and 665 respectively (Statistics Botswana 2014). Households were generally based at cattle posts which are individual family farms, with arable fields found close by. Cattle posts were found at regular intervals around and between the two villages. The main source of livelihood in this region was arable farming with 71.8% of households benefitting from this activity (Department of Environmental Affairs and Centre for Applied Research 2010). Most arable farming was for subsistence purposes with occasional sale of excess produce within communities (personal observation). Poverty levels were above average for Botswana with 38.5% of the population in the region living in poverty, earning less than BWP 572/month (US$57/month, BWP 1=0.1USD, calculated on 11/07/2018) (Department of Environmental Affairs and Centre for Applied Research 2010).

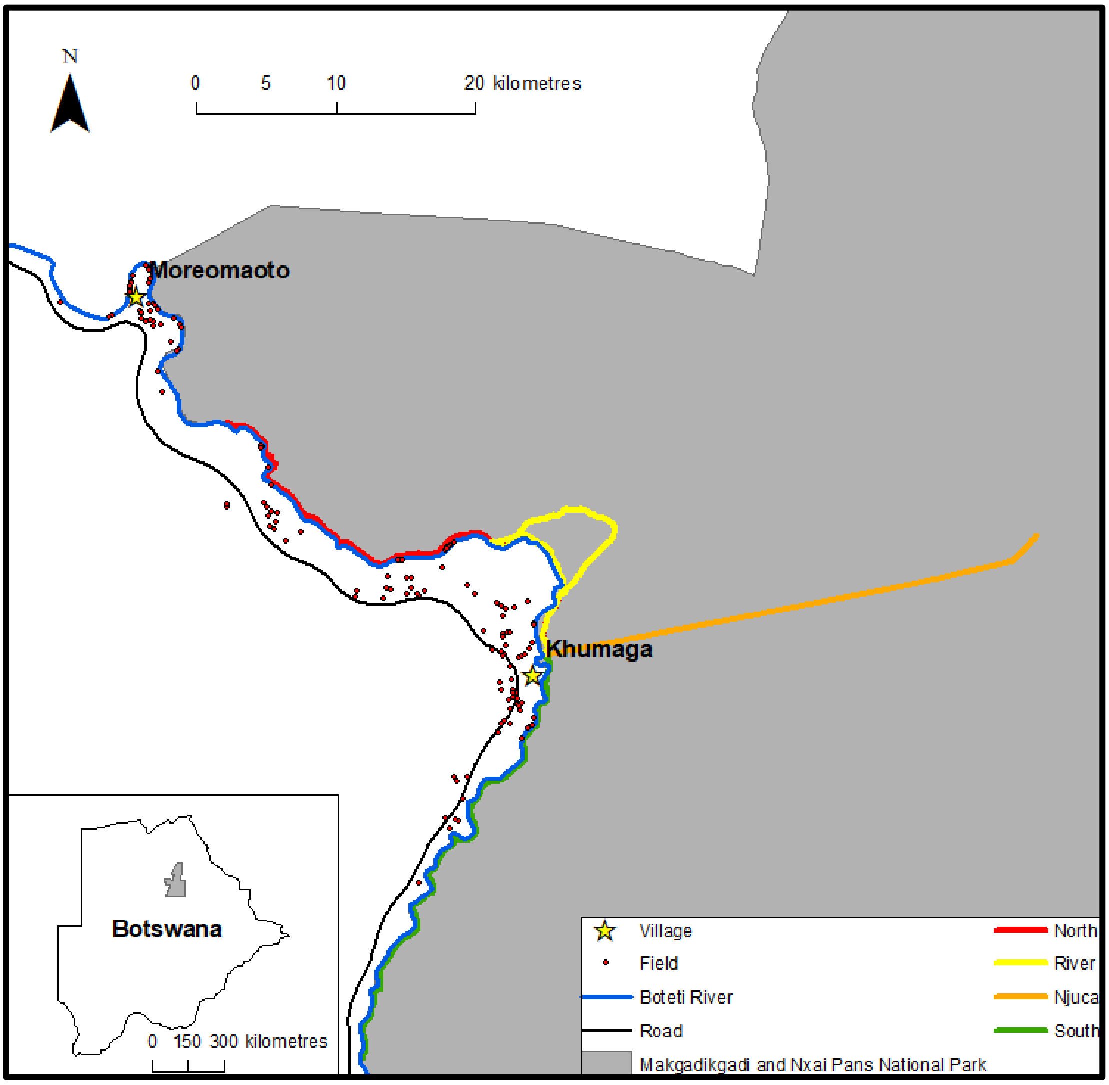

Figure 1.1. Map of study area

Unlike other areas in Africa, cattle were not herded in the Makgadikgadi region (Frank, Woodroffe & Ogada 2005; Hemson *et al.* 2009). Cattle were released from cattle posts in the morning to graze and returned in the evening for water (Hemson *et al.* 2009). While unattended, on occasions they strayed into fields causing damage to crops. There were two field types utilised in the region: standard rain-fed fields and molapo fields that were ploughed in the dry riverbed and utilised the receding river levels, providing water for crops (Venema & Kgaswanyane 1996). Two ploughing techniques were used by farmers in the region, broadcast and row planting. Broadcast planting is when seeds are scattered by hand or mechanically, and then incorporated by ploughing into the soil. Row planting is when a farmer ploughs lines in their field using either animal or mechanical power and then inserts the seeds into the soil at regular intervals along the line. Farmers received a bonus payment of P800/ha for row planting using either a tractor or animal draught power as an incentive to change from traditional broadcast methods.

Government programmes provided a safety net for communities. Arable farming was significantly subsidised in the region through the Integrated Support Programme for Arable Agricultural Development (ISPAAD). The programme was introduced in 2008 to increase grain production, promote food security at the household and national level, commercialise agriculture through mechanisation and facilitate access to farm inputs and credit (Ministry of Agriculture 2013). Support was provided through the provision of seeds, fertiliser and herbicide to cover up to 5ha.

1.8 Thesis rationale

My focus was to understand human-elephant interactions between local communities and a predominantly bull population of African elephants in a hotspot for negative human-wildlife interactions. My overall aim was to gain a better understanding of human-elephant interactions in the Makgadikgadi region at the local level by determining characteristics of crop-foraging events, identifying which elephants are involved, assessing the local communities' attitudes towards these interactions, identifying how farmers may influence events, and calculating an economic cost of these interactions for farmers.

While previous studies have looked at the impact of elephants on farmers and identified patterns to these impacts, these studies have often been completed across a large spatial scale. This provides information of interaction hotspots and broad patterns but management of negative interactions must be performed at the local scale, based on local patterns (Sitati, Walpole & Leader-Williams 2005). Management that is successful in one area is not necessarily guaranteed to succeed in another, so a balanced approach in management is required, taking account of global insights and local variability (Madden 2004). By investigating human-elephant interactions at the crop-foraging event level, it should be possible to identify patterns previously unidentified because of the large temporal scale placed on events. Of particular interest were patterns at the end of an agricultural season.

The uniqueness of a predominantly male elephant population in relation to crop-foraging events also provides an opportunity to understand the demographics of crop-foraging elephants, seeing how these demographics are influenced in relation to crop-foraging and identifying patterns of interactions. Previously such patterns have been difficult to identify because the difference between male and female elephant behaviour confounds interpretation. This natural separation by sex enables the main demographic of crop-foraging elephants to be studied further.

The subsistence nature of farming in the Makgadikgadi region also means that more than one crop is often grown in fields. This makes it possible to quantify the extent of damage of each crop in a field in relation to its availability to determine if elephants favour foraging on some crops more than others.

Farmers are one of the main stakeholder groups influenced by human-elephant interactions. Understanding farmers' attitudes towards wildlife is crucial when designing management practices and interventions. By gaining insights from one of the main stakeholder groups influenced by human-elephant interactions, attitudes can be assessed to determine whether particular factors influence attitudes within a stakeholder group rather than identify differences among stakeholder groups. Moreover, understanding when farmers complete certain farming practices might identify patterns that make them vulnerable to crop-foraging events. Finally, it is important to understand farmers' perceptions of crop-foraging events. Comparing these to actual outcomes identifies how aligned farmers are in their perceptions and whether they act on these perceptions.

Farmers have often been reported to overestimate the scale of human-wildlife interactions, from both the frequency of events, to the extent and value of damage (Hoffmeier-Karimi & Schulte 2014). Examining a government compensation scheme and farmers' estimates of their losses enables comparisons to be made between the two. While this is commonly undertaken in studies that ask stakeholders about their opinions on compensation (Bandara & Tisdell 2002; Hoffmeier-Karimi & Schulte 2014), determining accurate independent estimates of damage might identify if, and why, these differences exist.

1.9 Thesis plan

In chapter two I identify and quantify patterns of human-elephant interactions in the Makgadikgadi region. Specifically I: (i) identify whether spatial features of fields and their characteristics influence the quantity and value of damage occurring in a field during an agricultural season, (ii) identify if these features and temporal characteristics influence the quantity and value of damage occurring after a crop-foraging event, (iii) determine if crop-foraging events are influenced by the time of year or the lunar cycle, and (iv) determine the impact cattle have on crop damage.

In chapter three I determine the demographics and movement patterns of crop-foraging elephants. More specifically I: (i) determine the age and group size of crop-foraging elephants, (ii) identify if spatial and temporal aspects of crop-foraging events influence these demographics, and (iii) determine whether elephants target fields and certain crops within fields based on their movement patterns.

In chapter four I determine farmers' attitudes towards elephants while identifying whether farming practices are influencing crop-foraging events. More specifically I: (i) determine if farmers' characteristics and experiences with elephants influence their value for, and tolerance of, elephants, (ii) determine if the dates farmers complete certain farming practices influences crop-foraging events and the resulting damage, and (iii) determine if farmers' perceptions of crop-foraging events are aligned with actual events.

In chapter five I determine what influences the disparity in compensation estimates between farmers and compensation schemes, and why farmers may overestimate damage. Specifically I: (i) determine damage estimates for farmers, the government compensation scheme and scientifically calculated estimates, (ii) identify if there are differences between these estimates, and (iii) determine what factors might cause these differences.

In chapter six I review the status of human-wildlife interactions in the context of my study. I then identify the progress of addressing human-wildlife interactions by the global community and make suggestions for what needs to be focussed on if we are to coexist with wildlife.

Chapter 2. Quantifying and identifying patterns of human-elephant interactions in the Makgadikgadi region

2.1 Summary

- Human-elephant interactions are becoming a major threat to the survival of the African elephant, undermining conservation efforts. Identifying the patterns of the interactions is crucial for the development of management tools to reduce interactions.

- Crop-foraging events in the Makgadikgadi region were quantified, and patterns of interactions were examined across three years to identify factors that rendered fields susceptible to crop-foraging events and different magnitudes of damage.

- During an agricultural season, no factors were identified that influenced whether a field was entered by elephants, or the frequency with which a field was entered. Fields that were more isolated incurred larger areas of damage at the end of a field season. Furthermore, fields with higher crop diversity resulted in larger areas of damage and a higher cost of damage.

- Crop-foraging events were highly seasonal, with increasing events as the season progressed, peaking in April. The lunar cycle influenced the frequency of crop-foraging events, with fewer events occurring during the full moon phase.

- The presence of cattle following a crop-foraging event resulted in larger amounts of damage.

2.2 Introduction

The issue of human-elephant interactions is becoming increasingly significant in Botswana, as elephant ranges expand (DWNP 2012; Thouless *et al.* 2016), and larger areas of land are cultivated (UNDP-UNEP PEI 2013), resulting in greater areas of overlap between people and elephants. Identifying when and where interactions are likely to occur, and the intensity of damage, is crucial for wildlife managers to develop, direct and implement mitigation measures to reduce the interactions (Marchini 2014).

Patterns of interactions are complex, with crop-foraging events unevenly distributed in both space and time. Hotspots of events have been identified where fields are more prone to crop-foraging, while other areas remain unaffected. Patterns of spatial interactions have been identified at larger spatial scales in relation to high elephant densities (O'Connell-Rodwell *et al.* 2000), proximity to wildlife habitat and refuges (Graham *et al.* 2010), area under cultivation (Sitati *et al.* 2003; Graham *et al.* 2010), permanent water (Smith & Kasiki 2000) and human density (Guerbois, Chapanda & Fritz 2012). At the field scale, patterns are linked to guarding effort (Sitati, Walpole & Leader-Williams 2005), distance to elephant pathways (Songhurst & Coulson 2014; von Gerhardt *et al.* 2014) and farming practices (Sitati, Walpole & Leader-Williams 2005; Guerbois, Chapanda & Fritz 2012).

Temporal patterns of interactions have been found to be relatively predictable. Crop-foraging events have been observed to occur almost exclusively at night (Thouless 1994; Hillman-Smith *et al.* 1995; Kiiru 1995; Graham *et al.* 2010; Pittiglio *et al.* 2014; von Gerhardt *et al.* 2014), with seasonal trends linked to the maturation of crops in fields (Tchamba 1996; Hoare 1999a; Chiyo *et al.* 2005; Jackson *et al.* 2008; Sitienei, Jiwen & Ngene 2014) and the reduction in natural forage quantity and quality (Osborn 2004).

Patterns of interactions identified at larger spatial scales are useful for directing resources to crop-foraging hotspots to minimise interactions. However, few studies have investigated patterns of interactions in hotspot regions at the field level. This information is useful not only for conservation managers but also for individual farmers. Understanding which spatial factors or field characteristics make a field susceptible to being entered, or the intensity of crop-foraging events, is important when trying to minimise the events, while identifying temporal patterns of events is useful for knowing when to increase guarding effort.

Patterns of interactions in relation to damage in a field at the end of an agricultural season are often investigated. However, with seasonal patterns of interactions being identified, patterns of damage may be masked due to cumulative damage being recorded over multiple crop-foraging events during different periods in an agricultural season. Therefore, examining patterns of interactions at the crop-foraging event level may result in further patterns being identified.

Damage to crops in fields is not exclusively caused by elephants. Several wildlife species cause damage to crops over the course of an agricultural season, including primates (Hill 2000; Hill & Wallace 2012), hippopotamus (Gillingham & Lee 2003), bush pig (Hsiao *et al.* 2013), red-billed quelea *Quelea quelea* (Ainsley & Kosoy 2015), rodents (Dudley, Mensah-Ntiamoah & Kpelle 1992; Lahm 1996; Garriga *et al.* 2017) and insect pests such as the armoured ground cricket *Acanthoplus speiseri* (Mbata 1992). However, it is often the elephant that receives greater negative attention in relation to damage and impact (de Boer & Baquete 1998; Naughton-Treves 1998). Fields are often entered more frequently by other wildlife species, with smaller amounts of resulting damage (Lahm 1996; Naughton-Treves 1998). However, the impact of a single elephant visit to a farm, although rare, can be overwhelming (Naughton-Treves 1998; Sam, Haziel & Barnes 2002; Graham *et al.* 2010). Livestock also cause significant damage to fields, although farmers are more tolerant of this damage (Naughton-Treves 1998).

In this chapter, I use data collected from 141 fields and 375 crop-foraging events, attended over three years. My overall aim was to identify patterns to interactions in the Makgadikgadi region, to be able to inform wildlife managers and farmers when and where interactions are likely to take place, so that mitigation and resources can be directed effectively. I also wanted to provide farmers with key information that may reduce the magnitude of damage occurring in their fields to tolerable levels. Specifically, my aims were to determine:

- whether fields are susceptible to being entered based on their location and characteristics, and whether these features influence the quantity and value of damage occurring in a field over the course of an agricultural season
- if these features, as well as temporal characteristics, influence the quantity and value of damage occurring after a crop-foraging event
- if the frequency of crop-foraging events is influenced by the time of year or the lunar cycle
- the impact cattle have on crop damage

2.3 Methods

2.3.1 Crop-foraging events

Meetings were held in Khumaga and Moreomaoto in February 2014 to inform the community about the project. Community members were asked to call me whenever they experienced a crop-foraging event in their field. On most occasions, my local research assistant and I were able to visit the field within 24 hours of the call. To increase the number of calls I received, farmers were given a mobile network credit (BWP 10 per crop-foraging event).

The farmer's name, date the field was entered and the date we attended were recorded. The date of the crop-foraging event was used to determine which phase the moon was in. The lunar cycle was defined into four phases: full, waning, new and waxing. The full moon phase was defined as the night of the full moon, three nights before and three nights after. Similarly, the new moon phase was defined as the night of the new moon, three nights before and three nights after. The waning phase was defined as the nights between the full moon and new moon phase, with the waxing phase defined as the nights between the new moon and full moon phase.

The boundary of the field in relation to the barrier and any defences in the field were recorded. The location of the corners of the field were mapped using a Garmin GPSmap 62s (Garmin Europe Inc., Southampton, UK) and later a GPS point was created for the centre of the field. GPS coordinates for the corners of fields were exported to Google Earth Pro. The ruler tool was used to trace the boundary of the fields, calculating the perimeter (kilometres) and area (hectares). The GPS coordinate for the centre of the field was exported to ArcGIS (Version 10.4.1). The NEAR tool was used to calculate the distance (metres) of each field to the Boteti River (boundary of the MPNP) and the nearest field.

The total ploughed area of the field was measured by pacing the length and width. My mean pace length was used to convert the paced area to metres squared which was converted to hectares (Table S2.1). If cattle had entered the field this was recorded. The field's crop composition was visually determined following the IUCN data collection and analysis protocol for human-elephant conflict situations in Africa (referred to as "IUCN method" in the rest of my thesis) (Hoare 1999b).

Damage was measured following the IUCN method (Hoare 1999b) across all three years (Figure 2.1). The dimensions of the damaged portion of the field were recorded by pacing around the damage. However, in most cases large areas of crops were not damaged. For this reason, I recorded the damage in paces by tracking the elephant through the field, recording whether the crops were damaged at each footfall. The paced area was converted to hectares. Using the total damaged area, total ploughed area, crop composition and the value of each crop per hectare defined by the DWNP (Table S2.2); the area, percentage and value of damage in a field could be calculated for each crop-foraging event, and for each field at the end of the agricultural season (see supplementary information 1 for detailed calculations).

Figure 2.1. Examples of elephant damage in two fields

The IUCN method provided a quick way to determine the general extent of damage and allows standardised results to be compared across regions, hence it is the recommended method for assessing elephant damage. However, the method did not allow fine scale damage or the identity of damaged crops to be determined. In 2015 and 2016 I used a line transect method developed by Chamberlain (2016) (referred to as "transect method" in the rest of my thesis). Line transects covering 2.5% of a fields ploughed area were found to be a representative sampling intensity (Chamberlain 2016). Transects were completed by Amy Chamberlain in 2015 and myself in 2016.

A random number method was employed to determine a start point for the transects. Two lists of random numbers were generated in Microsoft Excel. The first list was used to determine the direction of the transect. This generated numbers from one to eight in reference to the eight cardinal and ordinal points of direction on a compass. The second list generated numbers from 1 to 30 in reference to the number of paces that needed to be walked. Thus, from the middle of the field a random direction to walk was chosen and then a random number of paces were walked. This was completed five times to determine the start point of the first transect. A final random direction was chosen to determine the direction of the first transect. If multiple transects were required, this method was employed to determine the start point of subsequent transects, although the starting point was the end of the completed transect, rather than the middle of the field. To ensure efficiency and minimal disruption to the farmer, transect lengths were determined by the minimum width of the field, such that the fewest number of transects were completed to survey 2.5% of the field.

When completing transects for the first time in a field, at each footfall, the plant closest to the foot (within one pace) was recorded (to determine crop composition), and whether it had been damaged by elephants or cattle, through browsing or trampling. If no plants were present within one pace of the footfall it was recorded as bare space. When attending subsequent crop-foraging events in the same field, only plants that were damaged at each footfall were recorded. Although planting densities may differ between crops and fields, it was assumed that a single plant occupied one pace-squared. Farmers would often employ a pacing technique when sowing seeds. The total number of damaged plants for each crop in a field was calculated by extrapolating the 2.5% sample estimate of damage. Using this estimate it was possible to calculate the area, percentage and value of damage for each crop-foraging event, and in the field at the end of the agricultural season (see supplementary information 1 for detailed calculations).

Having calculated the crop composition following both the IUCN and transect method, I calculated the crop diversity for fields using the Shannon-Weiner index:

$$H' = -\sum pi \ln(pi)$$

where pi is the proportion of individuals for each crop species present in the field. The crop diversity was calculated for each field. When analysing data at the crop-foraging event level, species compositions were recalculated after each crop-foraging event to account for crops being damaged and therefore, crop diversity changing.

2.3.2 Fields not entered by elephants

It was important to gather information on fields not entered by elephants. I used government agricultural registers to identify fields that had been ploughed that agricultural season. I visited these fields and collected all the information outlined in section 2.3.1 (except damage estimates).

2.3.3 Accounting for spatial autocorrelation

Incidences of human-wildlife interactions are rarely distributed evenly across a landscape. This is particularly true for human-elephant interactions when it takes the form of elephants entering fields, as crop-foraging events are often spatially clustered. For example, an elephant or elephants may enter more than one field in a night, and their behaviour can be influenced by the attributes of other fields nearby. Adjacent fields can share similar values and are not completely independent of each other, an assumption for many statistical tests. This can reduce the degrees of freedom, increasing the chances of type I errors (Legendre & Legendre 1998), due to correlation coefficients appearing more significant than they are. Using all crop-foraging event data assumes there is no spatial autocorrelation, which is unlikely to be the case, although for management purposes this may be a cost-effective method requiring less time for analysis (Graham *et al.* 2010). Other studies try to remove spatial autocorrelation by taking a sub-sample of the data, such as selecting one field entered, on a particular night, in a particular location (Sitati, Walpole & Leader-Williams 2005). If sample sizes are large enough it may be possible to average away spatial autocorrelation using mixed effects models (Guerbois, Chapanda & Fritz 2012). Some studies use grids with different spatial scales to select data for analysis on the basis that as the grid cells become larger, the chances of spatial autocorrelation decrease as fields being selected are further from one another.

I decided to use the average distance elephants move during a day as a guide for how far they may travel in one night while foraging on crops. Although an elephant can travel up to 60km in a day, average straight-line distances travelled range between 3km/day in the wet landscapes to 6km/day in the dry (Loarie, Van Aarde & Pimm 2009), with elephants that foraged on crops ranging 3.3km daily in Kibale National Park, Uganda (Chiyo & Cochrane 2005). I decided to sub-sample my crop-foraging event data at a 2.5km limit to identify potential spatially autocorrelated crop-foraging events. To do this, I identified all the days when multiple crop-foraging events had occurred. I identified the fields involved and used Garmin MapSource (Version 6.16.3) to record which fields were within 2.5km of each other. Crop-foraging events where the fields were within these distances were considered to be dependent, and therefore likely to cause spatial autocorrelation. One crop-foraging event was randomly selected using a random number generator in Microsoft Excel and kept in the dataset, the other crop-foraging event(s) were removed. Removing spatial autocorrelation at the 2.5km scale resulted in 114 (30.6%) crop-foraging events being removed. Considering average daily movement in wet landscapes is 3km/day and the average field is 1.1km from the boundary of the MPNP, it is likely that removing crop-foraging events at this scale would be appropriate.

2.3.4 Ethics and permits

The study was undertaken under an approved research permit from the Ministry of Environment, Wildlife and Tourism Botswana (Permit number: EWT 8/36/4 XXVI (8)). Supplementary permits for working inside the MPNP were approved each year by the DWNP.

The work carried out was purely observational. Ethics clearance from the University of Bristol was approved (UIN number: U/14/005). Research ethics approval was granted from the University of Bristol for working with human participants.

At the beginning of the project I received approval from the village Kgosi's (Chiefs) in both Khumaga and Moreomaoto to conduct my research.

2.3.5 Data analysis

All analyses were performed in R (version 3.3.2). Not all fields were used in the analyses because it may not have been possible to determine certain variables for some fields, hence sample sizes varied depending on the variables analysed. Patterns of interactions were analysed using mixed models fit by maximum likelihood using "lme4" (Bates *et al.* 2015). I selected the best model error structure based on Akaike's Information Criterion (AIC), where a lower AIC indicates a better model fit (Burnham & Anderson 1998; Motulsky & Christopoulos 2003). I used likelihood ratio tests for stepwise model refinement to identify the minimal model that contained only significant fixed effects, and the associated Chi-square values are reported.

Damage scores (ha damage and value of damage) were determined following the transect method. Cattle were able to enter fields as a result of elephants breaching barriers. Therefore, damage scores included both elephant and cattle damage.

To investigate whether spatial (distance from the MPNP; distance to nearest field) or field (boundary; crop diversity; area of field) characteristics influenced whether a field was entered, the frequency of entry, area and value of damage at the end of the agricultural season, I used generalised linear mixed models (GLMMs) with "year" included as a random effect to account for the same fields being monitored in multiple years. All fields were included when determining factors influencing whether a field was entered or not. However, when determining which factors influence the frequency of entry, area and value of, damage, only fields that were entered were included in the analysis. Summaries of full models are shown in Table 2.1.

To investigate whether spatial, field or temporal (moon phase; month) characteristics influenced the area and value of damage after a crop-foraging event, I used generalised linear mixed models (GLMMs), with "field ID" nested within "year" as a random effect to account for multiple crop-foraging events in the same field, in the same year, being dependent of each other. I used all crop-foraging events having accounted for spatial autocorrelation (section 2.3.3). Summaries of full models are shown in Table 2.2.

When investigating spatial patterns for both fields and crop-foraging events, one field was removed, resulting in the removal of two crop-foraging events, as it was a potential outlier with a high value for distance to nearest field linked to its remoteness in the study area.

The frequency of crop-foraging events was determined for each month and moon phase having accounted for spatial autocorrelation. A Chi-square test was used to determine if differences existed between months and moon phases for each year of the study, and by grouping the data from all three years.

To determine the impact of cattle on crop damage, the percentage, area and value of damage in a field at the end of an agricultural season were compared for fields that had and had not been entered by cattle using a Mann-Whitney U test. I analysed data collected using both the IUCN and transect method.

Table 2.1. Full generalized linear mixed models for identifying patterns of crop-foraging at the end of the agricultural season

Model	Data set	Response	Fixed effect	Random effect	Model family
1	All fields	entered (yes/no)	distance from the MPNP, distance to nearest field	year	binomial (link=logit)
2	All fields that were entered	number of crop-foraging events	distance from the MPNP, distance to nearest field	year	negative binomial (link=log)
3	All fields that were entered	area of field damaged (ha)	distance from the MPNP, distance to nearest field	year	lognormal (Gaussian with $\log_{10}$+1 transformed response variable)
4	All fields that were entered	value of damage (BWP)	distance from the MPNP, distance to nearest field	year	lognormal (Gaussian with $\log_{10}$+1 transformed response variable)
5	All fields	entered (yes/no)	boundary type; crop diversity; area of field	year	binomial (link=probit)
6	All fields that were entered	number of crop-foraging events	boundary type; crop diversity; area of field	year	negative binomial (link=log)
7	All fields that were entered	area of field damaged (ha)	boundary type; crop diversity	year	lognormal (Gaussian with $\log_{10}$+1 transformed response variable)
8	All fields that were entered	value of damage (BWP)	boundary type; crop diversity	year	lognormal (Gaussian with $\log_{10}$+1 transformed response variable)

Table 2.2. Full generalized linear mixed models for identifying patterns of crop-foraging at the crop-foraging event level, outlining the fixed and random effects, and the model family used

Model	Data set	Response	Fixed effect	Random effect	Model family
9	All crop-foraging events	area of field damaged (ha)	distance from the MPNP; distance to nearest field	year*field ID	lognormal (Gaussian with $\log_{10}$+1 transformed response variable)
10	All crop-foraging events	value of damage (BWP)	distance from the MPNP; distance to nearest field	year*field ID	lognormal (Gaussian with $\log_{10}$+1 transformed response variable)
11	All crop-foraging events	area of field damaged (ha)	crop diversity; boundary type	year*field ID	lognormal (Gaussian with $\log_{10}$+1 transformed response variable)
12	All crop-foraging events	value of damage (BWP)	crop diversity; boundary type	year*field ID	lognormal (Gaussian with $\log_{10}$+1 transformed response variable)
13	All crop-foraging events	area of field damaged (ha)	moon phase; month	year*field ID	lognormal (Gaussian with $\log_{10}$+1 transformed response variable)
14	All crop-foraging events	value of damage (BWP)	moon phase; month	year*field ID	lognormal (Gaussian with $\log_{10}$+1 transformed response variable)

2.4 Results

2.4.1 Field characteristics

I visited 141 fields during the three-year study. On average a field was 1060m (range 4-3472, SD 936) from the Boteti River which acted as the boundary of the MPNP, with the average distance between fields being 422m (range 60-4191, SD 513). Field sizes varied with an average size of 2.9ha (range 0.2-21.6, SD 3.2) and a 0.6km perimeter (range 0.2-2.0, SD 0.3). Farmers ploughed on average 1.7ha of their field (range 0.1-14.7, SD 2.2). Most fields (73.5%) had an acacia fence field boundary, while 9.6% had a wire fence and 16.9% had both a wire and acacia fence boundary.

I recorded 13 different crops planted in the fields visited. The average field had 4.8 crops (range 1-8, SD 1.3) (Table S2.3). Maize was planted in more than 90.0% of fields, watermelons and cowpeas in more than 80.0% of fields, sweet reed and millet in over half, and pumpkins and sorghum in more than 40.0%. Groundnuts, lablab, butternut, tomatoes, green pepper and chilli pepper were only grown in a few fields (Table S2.3). The average Shannon's Diversity Index score for a field was 1.1 (range 0.0-1.9, SD 0.4) following the IUCN method, and 1.0 (range 0.0-1.8, SD 0.4) for the transect method. There were no significant differences between diversity scores calculated following the IUCN or transect method (paired t-test: t=0.166, d.f.=48, P=0.869) (Table S2.4).

The transect method allowed the calculation of area of bare space: on average 40.8% of a ploughed area was bare. The average field, using data from all three years, was valued at BWP 5400 (range 68-36,454, SD 6701), following the IUCN method. In 2015 and 2016 the average field value was BWP 2590 (range 55-17,086, SD 2941), using the transect method.

2.4.2 Crop-foraging event characteristics

I attended 375 crop-foraging events over three years. On average, a field was entered 2.4 times a season (range 0-21, SD 3.1). However, when only using data from fields that were entered, this increased to 3.2 times a season (range 1-21, SD 3.2), resulting in significant damage (Table 2.3). Over the three years, cattle caused damage in 34.4% of fields and were involved in 22.1% of crop-foraging events.

Table 2.3. Extent of damage to crops in fields following both the IUCN and transect method, at the end of the agricultural season and after a crop-foraging event

End of agricultural season	Method	
	IUCN	Transect
Percentage	23.9% (range 0.0-100.0, SD 39.0)	46.3% (range 0.0-100.0, SD 36.4)
Area	0.3ha (range 0.0-5.6, SD 0.9)	0.2ha (range 0.0-1.0, SD 0.3)
Value	BWP 512 (range 0-6605, SD 1329)	BWP 773 (range 0-3658, SD 1026)
Crop-foraging event		
Percentage	14.5% (range 0.0-100.0, SD 31.5)	18.1% (range 0.0-100.0, SD 25.1)
Area	0.2ha (range 0.0-5.6, SD 0.7)	0.1ha (range 0.0-1.0, SD 0.1)
Value	BWP 305 (range 0-6605, SD 1026)	BWP 336 (range 0-3625, SD 563)

2.4.3 Factors influencing aspects of crop-foraging

No spatial or field characteristics influenced whether a field was entered or not, and if entered, the frequency of crop-foraging events (supplementary information 1: models 1, 2, 5 and 6).

The distance from the field to the MPNP did not have a significant effect on the area of crop damage, either in combination with distance to the nearest field (distance from the MPNP removed from the full model Δdeviance=0.520, d.f.=1, *P*=0.471) or by itself (distance from the MPNP model compared to null model Δdeviance=2.498, d.f.=1, *P*=0.114). However, the distance to the nearest field influenced the area of damage, with increasing distance between fields resulting in increased area of damage (distance to the nearest field model compared to null model Δdeviance=4.731, d.f.=1, *P*=0.030). However, the model only explained 7.0% of the variation in the area of damage, resulting in a small effect (Table 2.4).

Table 2.4. Results of a lognormal LMM investigating the effect of distance to nearest field and distance from the MPNP on the total area of a field damaged at the end of an agricultural season. Coefficients (β) are reported on the $\log_{10}$ scale. Significant *P*-values for fixed effects included in the minimal model are shown in bold. Unit of analysis=ha. Sample size=64 fields

Model parameter	**β**	**SE**	**t**	**x^2**	**df**	***P***
Fixed effects						
Intercept	0.035	0.016	2.262			
Distance to nearest field	<0.001	<0.001	2.181	4.731	1	**0.030**
Non-significant fixed effects						
Distance from the MPNP				2.498	1	0.114
Random effects	Variance	SD				
Year (N=2)	<0.001	<0.001				

The type of boundary did not significantly influence the area of damage caused by elephants at the end of the agricultural season, either in combination with crop diversity (boundary removed from full model Δdeviance=1.394, d.f.=2, *P*=0.498) or alone (boundary model compared to null model Δdeviance=2.171, d.f.=2, *P*=0.338). However, the crop diversity significantly influenced the area of damage, with increasing diversity resulting in increased damage (crop diversity model compared to null model Δdeviance=4.565, d.f.=1, *P*=0.033) (Table 2.5).

Table 2.5. Results of a lognormal LMM investigating the effect of boundary type and crop diversity on the area of damage at the end of an agricultural season. Coefficients (β) are reported on the $\log_{10}$ scale. Significant *P*-values for fixed effects included in the minimal model are shown in bold. Unit of analysis=ha. Sample size=51 fields

Model parameter	**β**	**SE**	**t**	**x^2**	**df**	***P***
Fixed effects						
Intercept	0.018	0.035	0.518			
Crop diversity	0.063	0.030	2.104	4.565	1	**0.033**
Non-significant fixed effects						
Boundary				2.171	2	0.338
Random effects	Variance	SD				
Year (N=2)	0.001	0.025				

Spatial characteristics of fields did not influence the value of damage (supplementary information 1: model 4). While crop diversity significantly influenced the value of damage, with increased crop diversity resulting in an increased value of damage (crop diversity model compared to null model Δdeviance=9.246, d.f.=1, *P*=0.002) (Table 2.6), the boundary did not influence the value of damage either in combination with crop diversity (boundary removed from full model Δdeviance=0.345, d.f.=2, *P*=0.841) or by itself (boundary model compared to null model Δdeviance=0.098, d.f.=2, *P*=0.952).

Table 2.6. Results of a lognormal LMM investigating the effect of boundary type and crop diversity on the value of damage at the end of an agricultural season. Coefficients (β) are reported on the $\log_{10}$ scale. Significant *P*-values for fixed effects included in the minimal model are shown in bold. Unit of analysis=BWP. Sample size=51 fields

Model parameter	**β**	**SE**	**t**	**x^2**	**df**	***P***
Fixed effects						
Intercept	1.255	0.354	3.544			
Crop diversity	1.088	0.349	3.121	9.246	1	**0.002**
Non-significant fixed effects						
Boundary				0.345	2	0.841
Random effects	Variance	SD				
Year (N=2)	<0.001	<0.001				

2.4.4 Factors influencing the extent and value of damage after each crop-foraging event

The area of damage was not influenced by any field characteristics or temporal characteristics of crop-foraging events (supplementary information 1: models 11 and 13). The distance to the nearest field did not influence the area of damage occurring after a crop-foraging event, either by itself (distance to nearest field model compared to null model Δdeviance=2.577, d.f.=1, *P*=0.108) or in combination with distance from the MPNP (distance to nearest field removed from full model Δdeviance=2.028, d.f.=1, *P*=0.154). However, the distance from the MPNP significantly influenced the area of damage, with larger areas of damage in fields further from the MPNP (distance from the MPNP model compared to null model (Δdeviance=5.735, d.f.=1, *P*=0.017) (Table 2.7). The model only explained 8.0% of the variation in the area of damage, resulting in a small effect size.

Table 2.7. Results of a lognormal LMM investigating the effect of distance from the MPNP and distance to nearest field, on the area of damage, during a crop-foraging event. Coefficients (β) are reported on the $\log_{10}$ scale. Significant *P*-values for fixed effects in the minimal model are shown in bold. Unit of analysis=ha. Sample size=88 crop-foraging events

Model parameter	**β**	**SE**	**t**	**χ^2**	**df**	***P***
Fixed effects						
Intercept	0.019	0.010	1.929			
Distance from the MPNP	<0.001	<0.001	2.448	5.735	1	**0.017**
Non-significant fixed effects						
Distance to nearest field				2.577	1	0.108
Random effects	Variance	SD				
Field: Year (N=39)	<0.001	0.020				
Year (N=2)	<0.001	<0.001				

Spatial characteristics of fields did not influence the value of damage after a crop-foraging event (supplementary information 1: model 10). However, the crop diversity of a field did influence the value of damage (crop diversity model compared to null model Δdeviance=11.825, d.f.=1, *P*=0.001) (Table 2.8), whereas the field boundary did not influence value of damage either in combination with crop diversity (boundary removed from full model Δdeviance=5.155, d.f.=2, *P*=0.076) or by itself (boundary model compared to null model Δdeviance=2.781, d.f.=2, *P*=0.249).

Table 2.8. Results of a lognormal LMM investigating the effect of crop diversity and field boundary on the value of damage, during a crop-foraging event. Coefficients (β) are reported on the $\log_{10}$ scale. Significant *P*-values for fixed effects included in the minimal model are shown in bold. Unit of analysis=BWP. Sample size=89 crop-foraging events

Model parameter	**β**	**SE**	**t**	**x^2**	**df**	***P***
Fixed effects						
Intercept	1.263	0.220	5.754			
Crop diversity	0.801	0.225	3.566	11.825	1	**0.001**
Non-significant fixed effects						
Boundary				5.155	2	0.076
Random effects	Variance	SD				
Field: Year (N=40)	<0.001	<0.001				
Year (N=2)	<0.001	<0.001				

The month of a crop-foraging event did not influence the value of damage, either by itself (month model compared to null model Δdeviance=4.946, d.f.=4, *P*=0.293), or in combination with moon phase (month removed from full model Δdeviance=9.209, d.f.=4, *P*=0.056). Although moon phase significantly influenced value of damage based on model simplification (moon phase model compared to null model Δdeviance=8.122, d.f.=3, *P*=0.044), *post hoc* tests revealed no significant difference in the value of damage between the different moon phases (Table S2.5).

2.4.5 Seasonality in elephant crop-foraging events

Crop-foraging events occurred between January and May in all three years, but the frequency of events differed significantly between months for each year (2014: X^2=146.090, d.f.=4, P<0.001; 2015: X^2=30.744, d.f.=4, P<0.001; 2016: X^2=40.730, d.f.=4, P<0.001) and when grouping all data from the three-year study (all years: X^2=160.590, d.f.=4, P<0.001) (Figure 2.2). For both 2014 and 2015 frequency was low in January, peaking in April in 2014 and March in 2015, with a low frequency of events in May. In 2016, the frequency of crop-foraging events also peaked in April but there was a high incidence in February and a low incidence in March. When looking at crop-foraging events across all three years there was a pattern of increasing crop-foraging events starting in January and peaking in April, with few events in May.

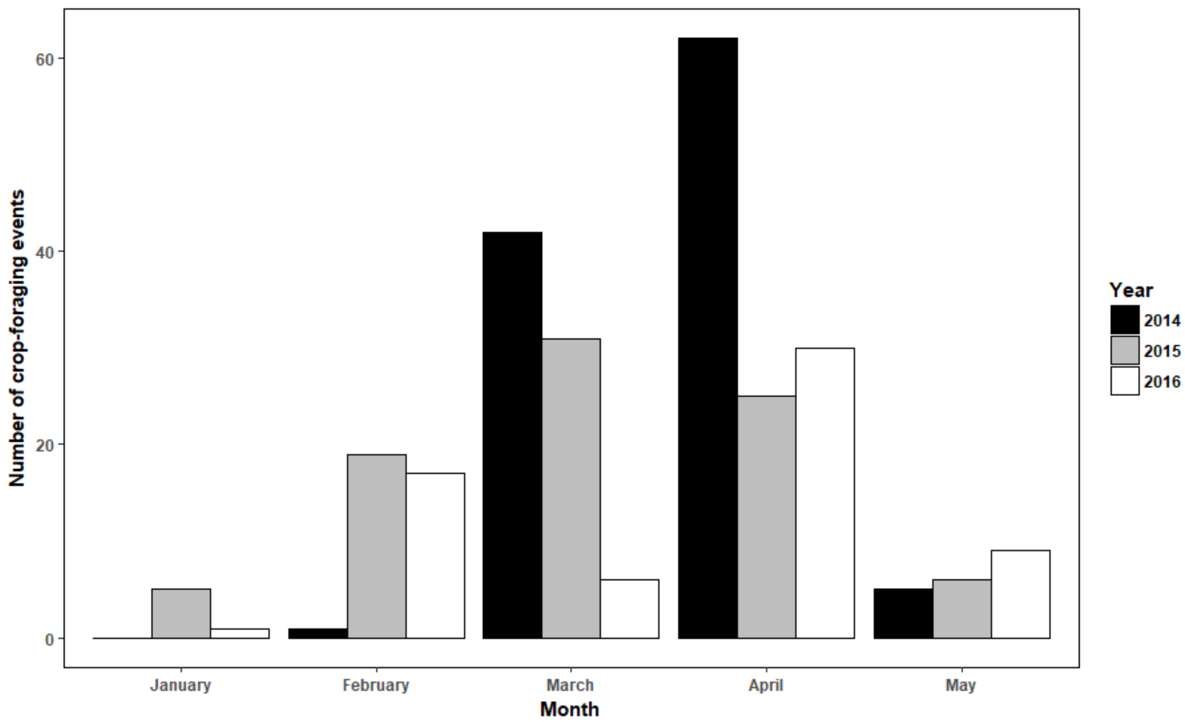

Figure 2.2. The number of crop-foraging events by month, having accounted for spatial autocorrelation in the Makgadikgadi region, Botswana, between February 2014 and May 2016 (n=259)

2.4.6 Lunar cycle and crop-foraging events

There appeared to be no significant difference in the frequency of crop-foraging events during different moon phases in 2014 (X^2=7.600, d.f.=3, *P*=0.055) or 2016 (X^2=2.206, d.f.=3, *P*=0.531). However, in 2015 the frequency of crop-foraging events differed significantly between moon phases, with fewer events occurring during a full moon (X^2=16.233, d.f.=3, *P*=0.001). When data from all three years were analysed together, there were significant differences between the frequency of crop-foraging events occurring during different moon phases (X^2=20.614, d.f.=3, P<0.001), with fewer occurring on nights during the full moon (Figure 2.3).

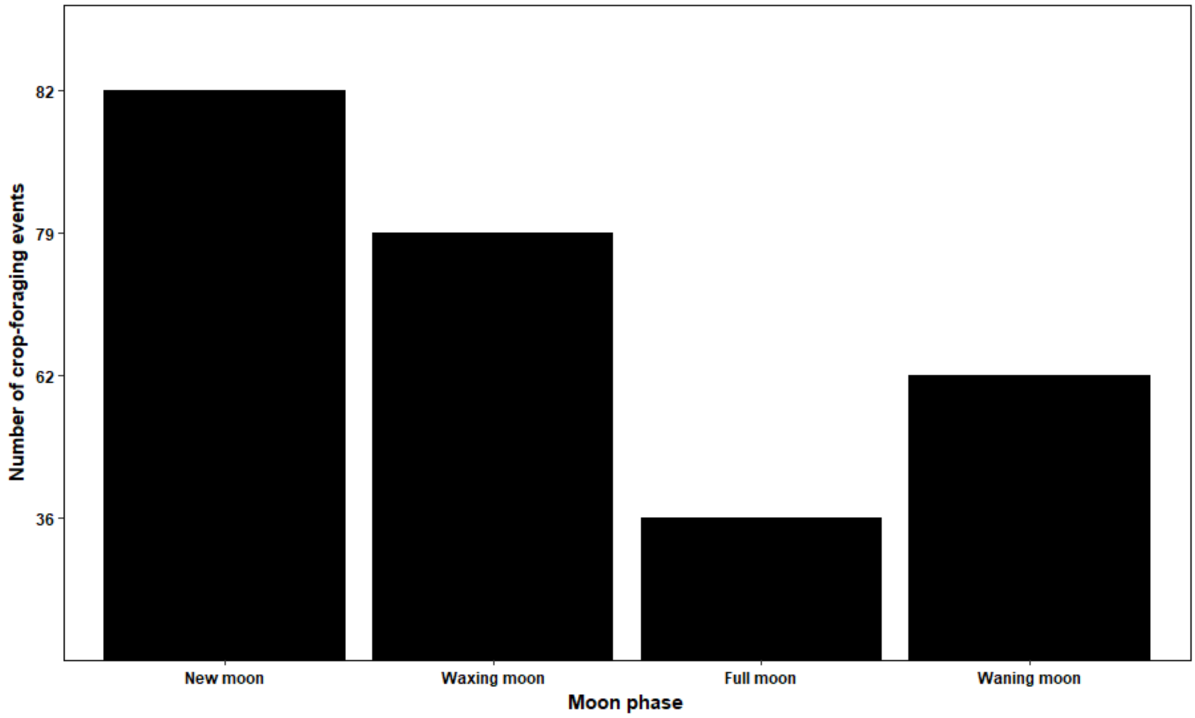

Figure 2.3. The number of crop-foraging events by moon phase, having accounted for spatial autocorrelation in the Makgadikgadi region, Botswana, between February 2014 and May 2016 (n=259)

2.4.7 Influence of cattle on crop damage

If a field had cattle enter during an agricultural season it resulted in a significantly higher percentage, area, and value of damage following both the IUCN and transect methods (Table 2.9).

Table 2.9. Impact of cattle on different aspects of damage following the IUCN and transect methods

Method	IUCN		Transect	
Cattle	Present	Absent	Present	Absent
Percentage	42.8% ± 9.0	3.0% ± 1.0	66.0% ± 6.1	22.1% ± 4.9
	Mann-Whitney U: $W_{26,27}$=169, P=0.001		Mann-Whitney U: $W_{30,24}$=607, P<0.001	
Area	0.6ha ± 0.3	<0.1ha ± <0.1	0.4ha ± 0.1	0.1ha ± <0.1
	Mann-Whitney U: $W_{22,25}$=100, P<0.001		Mann-Whitney U: $W_{26,24}$=541, P<0.001	
Value	BWP 1160 ± 516	BWP 107 ± 43	BWP 1252 ± 246	BWP 351 ± 89
	Mann-Whitney U: $W_{15,24}$= 69, P=0.001		Mann-Whitney U: $W_{26,24}$=470, P=0.002	

2.5 Discussion

None of the factors investigated significantly influenced either the risk of a field being entered or the frequency of entry during the agricultural season. However, fields that were more isolated and had a higher crop diversity incurred larger areas of damage, while increased crop diversity also increased the value of damage. After a crop-foraging event, fields further from the MPNP experienced larger areas of damage, and higher crop diversity resulted in a higher value of damage. Crop-foraging events showed temporal patterns, with increasing events as the season progressed, and fewer events occurring during a full moon. If cattle entered a field after elephants, the extent of damage increased significantly.

2.5.1 Can vulnerable fields be identified in a crop-foraging hotspot?

Identifying areas that have increased probability of human-elephant interactions is important for management purposes. However, this is often investigated at large spatial scales, with the occurrence of crop-foraging events being linked to the area under cultivation, proximity to towns, settlement density or where villages border protected areas with high densities of elephants (O'Connell-Rodwell *et al.* 2000; Sitati *et al.* 2003; Graham *et al.* 2010). Identifying hotspots enables resources to be distributed effectively. However, for an individual farmer, identifying that a field is in a hotspot is not helpful. I therefore investigated patterns of interactions at the individual field scale, within a hotspot, to determine if factors relating to a field's location and characteristics influenced different aspects of crop-foraging.

All fields in the Makgadikgadi region were vulnerable to being entered, irrespective of their location or characteristics. Larger, more isolated farms are entered more often due to inadequate guarding effort and less human activity (Barnes *et al.* 2005; Sitati, Walpole & Leader-Williams 2005). However, little guarding took place in the region, so deterring elephants from entering fields was unlikely to play a role, irrespective of field size and proximity to nearby fields. The high proportion of fields entered by elephants meant there was low predictive power in identifying differences between fields that were and were not entered. The high probability of male elephants involved in crop-foraging in the region may explain the difficulty in identifying patterns to interactions due to their unpredictable behaviour, described as the "male behaviour hypothesis" (Hoare 1999a). However, it is more likely that within a hotspot for human-elephant interactions all fields are vulnerable to being entered.

Although spatial patterns were not identified, it might have been anticipated that a field's boundary may influence entry into fields. Although an acacia or wire fence acts as a barrier to entry, their function is to demarcate field boundaries rather than act as barriers to elephants. If barriers are to reduce crop-foraging, there needs to be a negative conditioning effect to deter entry. Electric fences can have positive results (O'Connell-Rodwell *et al.* 2000; Graham *et al.* 2009b), although they are costly (O'Connell-Rodwell *et al.* 2000; Kioko *et al.* 2008), require maintenance (O'Connell-Rodwell *et al.* 2000) and are still broken by elephants (Graham *et al.* 2009b; Mutinda *et al.* 2014). Likewise, deterrents such as chilli fences and the burning of chilli can deter elephants from entering fields (Sitati & Walpole 2006; Pozo *et al.* 2017). Although some farmers had deterrents in place, the varying levels of effort by farmers across the season and between farmers meant that it was not possible to test the effects of deterrents. Often more than one deterrent was used and therefore concluding the efficacy of a single deterrent would have been difficult.

Once inside a field few factors were likely to influence crop-foraging. Isolated fields may incur less human disturbance, allowing elephants and cattle to remain in fields longer, increasing consumption of crops. High crop loss in areas of Assam, India, where field guarding is lower, has been attributed to elephants' sense of security (Wilson *et al.* 2015). Due to the subsistence nature of farming in the Makgadikgadi region, fields were heterogeneous with a wide variety of crops planted. Elephants may spend more time foraging in fields with a greater range of crops, not only causing greater browsing but also trampling damage. While fields with many types of crops are at greater risk of entry (Barnes *et al.* 2005; Sam *et al.* 2005), I did not observe crop diversity influencing the frequency of crop-foraging events.

The premise of this study was to understand patterns to crop-foraging that would be useful for farmers for the reduction of crop losses. This meant including damage caused by cattle in estimates. However, this may have resulted in "noise" in the data, making it difficult to identify patterns in relation to the extent of damage. Further research using fields that were only entered by elephants may result in patterns to elephant damage being identified. However, while this would be interesting for research purposes, a farmer is only going to be influenced by the total damage in their field, as that is ultimately what influences attitudes.

2.5.2 Temporal patterns of crop-foraging events in the Makgadikgadi region

Determining when interactions are likely to take place is important for wildlife managers and farmers with regard to increasing guarding efforts and mobilising resources to assist farmers. I investigated temporal patterns to crop-foraging events across agricultural seasons and the influence of the lunar cycle on events.

While temporal factors did not influence the extent of damage occurring during crop-foraging events, interactions were highly seasonal, with events peaking in April, and reduced events during the full moon phase. There are two hypotheses regarding the onset of crop-foraging. The first suggests that as natural forage quality and availability declines at the end of the wet season, elephants leave the safety of protected areas due to nutritional stress and enter fields to meet their energy requirements (Osborn 1998). The second hypothesis suggests that the maturing or ripening of crops in fields, providing an abundance of nutritious and palatable forage, which is likely to be driven by rainfall, triggers the onset of crop-foraging (Hillman-Smith *et al.* 1995; Bhima 1998). Identifying the trigger for the onset of crop-foraging in the Makgadikgadi region is difficult. The region has defined wet and dry seasons resulting in seasonal fluctuations of natural forage quality influencing the physical body condition of elephants (Pitfield 2017). However, bull elephants are able to travel further from water and utilise a wider range of habitats, resulting in them being less susceptible to reduced forage quantity and quality (Stokke & du Toit 2002). While seasonal patterns were observed in the region, determining what influences them requires further research.

The influence of the lunar cycle on patterns of crop-foraging is probably linked to risk avoidance behaviours: elephants move faster through human-dominated landscapes (Douglas-Hamilton, Krink & Vollrath 2005; Graham *et al.* 2009a), avoid areas of human settlement (Hillman-Smith *et al.* 1995) and areas easily accessible to poachers (de Boer *et al.* 2000). Elephants almost exclusively enter fields at night (Thouless 1994; Hillman-Smith *et al.* 1995; Sitati *et al.* 2003; Barnes *et al.* 2007; Graham *et al.* 2009a). My finding that the frequency of crop-foraging events was significantly reduced during the full moon phase agrees with those of Gunn *et al.* (2014). Full moons result in greater illumination of the surroundings, potentially increasing farmers' ability to detect elephants, while Barnes *et al.* (2007) suggest it is the increased guarding effort on nights during a full moon that increases the perception of risk. Fields in the Makgadikgadi region are often unguarded and therefore the patterns identified in this study are probably due to elephants avoiding the risk of detection rather than increased guarding efforts.

Although temporal factors influenced the occurrence of crop-foraging, these factors are unlikely to influence the extent of damage when events take place. Once risk is taken and elephants enter a field, they are likely to forage normally, irrespective of the moon phase or time of year. While it might be expected that more damage occurs later in the agricultural season when crops are mature (Tchamba 1996), trampling damage occurs when elephants are present in a field irrespective of the stage of crop development, and this may explain why month did not influence damage. Identifying how the type of damage changes over the course of the agricultural season might identify patterns currently hidden when just analysing damage in general.

Further research in the Makgadikgadi region might identify which factors trigger the onset of crop-foraging behaviour. By monitoring forage availability and quality inside the MPNP, alongside crop maturity in fields, it may be possible to determine what causes the onset of crop-foraging behaviour. The high variation in timing of crop maturity within and between fields might result in difficulty identifying patterns. However, determining if there is a transition from trampling to browsing damage across a season might add additional evidence. For the present, the fact that crop-foraging frequency increases steadily between January and April offers the opportunity for farmers to establish deterrent strategies in early February and maximise guarding activity in March and April to increase their harvest, with less vigilance required during the full moon phases.

2.5.3 How much of the blame should be placed on elephants?

Elephants are often the main species blamed for damage to crops. However, damage to crops can be caused by many wildlife species (Mbata 1992; Hill 2000; Gillingham & Lee 2003) and in multiple use landscapes, domestic livestock can cause damage. It is therefore important when quantifying damage to identify the species involved.

The presence of cattle in the Makgadikgadi region significantly increased the extent of damage in fields. Cattle damage can be comparable, even exceeding wildlife damage (Naughton-Treves 1998). Cattle are released from cattle posts and left unattended in the morning to graze and return in the evening for water. On some occasions they do not return, leaving them able to access breaks in field boundaries created by elephants during the night. When attending crop-foraging events, cattle were often found in the field and would remain until forcibly removed (personal observation). The presence of cattle greatly exacerbates the negative interaction, with the perception that elephants are damaging larger areas of crops. While there would be fewer opportunities for cattle to access fields if elephants were not in the area, on some occasions cattle still entered in the absence of elephant damage.

Managing livestock in the region is crucial. Emphasis should be placed on ensuring cattle are kraaled (placed in an enclosure) at night. Moreover, fields should be checked to ensure any breaches in the boundary are detected and repaired swiftly. Further research could investigate why damage caused by cattle is more readily tolerated. Cattle play an important role in Botswana culture: they are an economic investment and represent the wealth and status of a person within their local community (Mordi 1989). Tolerance for cattle damage might be a result of customary law between farmers, with the owner of damage-causing cattle being required to compensate damage caused to another farmer’s field. Elephants are often viewed as belonging to the government, and farmers believe the government do not take responsibility for them, which probably influences tolerance (DeMotts & Hoon 2012).

2.6 Conclusions

Human-elephant interactions are unlikely to be resolved completely. Therefore, conservation managers, practitioners and researchers should aim to reduce interactions to tolerable levels. All fields in the Makgadikgadi region were vulnerable to being entered by elephants. However, some factors influenced the amount of damage. In areas where crop-foraging is high, emphasis should be placed on advising farmers about traditional, farm-based mitigation strategies that may reduce both the occurrence and frequency of crop-foraging events. Farmers also need to understand about the characteristics of fields that influence the amount of damage, especially when the subsistence nature of farming in the region might render farmers vulnerable to large amounts of damage. My data suggest that if diversity was reduced to one or two staple crops, the attractiveness of fields to elephants might be reduced.

The identification of seasonal patterns to crop-foraging may allow farmers to limit the amount of damage to fields by increasing vigilance when interactions are likely to be high, both seasonally and in relation to the moon phase. The influence of the lunar cycle provides an interesting opportunity to investigate mitigation strategies that may manipulate perceived light levels. Solar lights in fields may deter elephants from entering due to perceived risk of human detection. If farmers in the region were to change their guarding practices and actively defend fields at night, moon phase could act as a simple guide for temporal variations in guarding practices. Finally, there needs to be a real improvement in pastoral practices to ensure that the damage caused by elephants is not exacerbated by livestock.

Chapter 3. Demographics and movement patterns of crop-foraging elephants

3.1 Summary

- Determining which elephants are likely to forage on crops, and why and how they move through the landscape, is integral to developing strategies to reduce human-elephant interactions.

- The demographics of crop-foraging elephants were identified, and factors were examined to determine what influenced these demographics. Movement trajectories of crop-foraging elephants were recorded to understand how elephants moved in a human-dominated landscape and how spatial and temporal factors influenced this movement.

- The group size of crop-foraging elephants did not differ from that of elephants inside the MPNP. Group sizes of crop-foraging elephants did not change as the agricultural season progressed, but elephants entered fields in larger groups as the distance from the MPNP increased.

- Crop-foraging events predominantly involved older male elephants more than would be expected based on demographics of the overall population. The age of crop-foraging elephants was not influenced by the distance of the field from the MPNP or by season.

- Movement of crop-foraging elephants towards fields was linear and directed, while movement inside fields was tortuous. Movement trajectories towards/within fields did

not change as the agricultural season progressed, and nor did trajectories differ within different crops.

3.2 Introduction

Understanding which elephants are involved in foraging on crops and how they move in a human-dominated landscape is crucial to identifying how to mitigate human-elephant interactions. Although female elephants will forage on crops (Smith & Kasiki 2000; Sitati *et al.* 2003), a large proportion of crop-foraging events involve male elephants (Hoare 1999a; Nyhus, Tilson & Sumianto 2000; Williams, Johnsingh & Krausman 2001; Jackson *et al.* 2008; Ahlering *et al.* 2011; Chiyo *et al.* 2011c; von Gerhardt *et al.* 2014). Of the male elephants that forage on crops, a large proportion are older adults and it has been argued that this is a high-risk, high-gain foraging strategy (Chiyo & Cochrane 2005; Chiyo, Moss & Alberts 2012). Elephants foraging on crops are maximising their nutrient intake, while minimising foraging effort through reduced time spent foraging and distance travelled. However, studies that conclude that the high proportion of crop-foraging events involve older males generally fail to account for the demographics of the source population.

It can be difficult to identify the demographics of crop-foraging elephants because they primarily forage on crops at night (Gunn *et al.* 2014). Previous studies have relied on indirect methods such as foot-print diameter and dung size to estimate elephant age (Chiyo & Cochrane 2005), tracking them to get direct observations (Chiyo *et al.* 2011c), or sexing and aging elephants by using camera traps on trails leading towards fields (Smit *et al.* 2017). While all these methods provide insights into crop-foraging elephants, there are limitations in ensuring a representative sample. Some elephants might not be detected by camera traps or those that were detected may not have foraged on crops. Likewise, elephant groups tracked from fields may have fused or split before being detected. So, relying on indirect observations of elephants away from the site of an event is likely to lead to error.

Crop-foraging can result in injury or death of elephants (Hoare 2000a; Obanda *et al.* 2008), and elephants foraging on crops have elevated stress levels in comparison to those in a national park (Ahlering *et al.* 2011). It is likely therefore that elephants would perceive crop-foraging to be risky (Hoare 2000a). They assess risk in a human-dominated landscape and demographics and movements adjust accordingly (Douglas-Hamilton, Krink & Vollrath 2005; Graham *et al.* 2009a; Chiyo *et al.* 2014; Gunn *et al.* 2014). Elephants involved in crop-foraging may increase or decrease group size to account for this perceived risk, while elephants may reduce crop-foraging activity in relation to increased perceived risk based on their age.

Although crop-foraging occurs throughout the agricultural season, in Botswana this peaks in April (chapter 2), which is likely to be linked to the maturation of crops. There are several hypotheses regarding how crop-foraging is learnt. These include trial and error or behaviour learnt from older bulls (Chiyo, Moss & Alberts 2012). Depending on how elephants learn crop-foraging, it might be anticipated that the demographics of crop-foraging elephants would change over the course of a growing season.

Movement patterns are likely to differ across a heterogeneous landscape and can provide a unique insight into how animals perceive their environment (Johnson *et al.* 1992; Dickson, Jenness & Beier 2005; Nams 2005). It has been anticipated that, in favourable habitats and landscapes, animals should move at low speeds with large turning angles, resulting in a more tortuous movement pathway to stay in a favourable region (Benhamou & Bovet 1989). In less favourable regions, animals should increase travel speed and reduce turning angles, resulting in a straight movement pathway. Elephants move differently in relation to resources, habitats, and landscapes: they move faster when outside protected areas (Douglas-Hamilton, Krink & Vollrath 2005; Graham *et al.* 2009a), spend more time in unprotected areas at night (Graham *et al.* 2009a), and show directed movement when travelling towards favourable habitat (Duffy *et al.* 2011). However, little is known about how elephants move when crop-foraging, and so it is unclear whether fields are targeted through goal-orientated, direct movement or found by random encounters. It should be possible to answer this question by studying the fine-scale movement of elephants. Likewise, elephants enter fields more frequently when particular crops are present, suggesting a preference for these crops (Sam *et al.* 2005). If this is the case, their foraging intensity is likely to increase in preferred crops. Most fields in the Makgadikgadi region contain a mixture of crops and so, if elephants forage on different crops at different intensities, it would be expected that their movement patterns within each crop type will vary, with higher intensity use resulting in more tortuous movement trajectories (de Knegt *et al.* 2007).

The Makgadikgadi region provides an opportunity to investigate the demographics of crop-foraging elephants and determine their movement patterns. The “soft” river boundary between the MPNP and communal lands permits the free movement of elephants. The high proportion of bulls inside the MPNP and flexible bull society provide an opportunity to examine determinants of group demographics for elephants foraging on crops, by comparing groups of elephants in the MPNP with those foraging on crops and determining whether movements to, and within, crop fields are directed.

In this chapter, I use data collected from 141 fields, 375 crop-foraging events and 1084 individual or group sightings of male African elephants inside the MPNP, collected over three years. My overall aim was to determine the demographics of elephants that forage on crops and understand how elephants move in relation to fields, in order that wildlife managers and farmers can identify which elephants to target with mitigation measures. Specifically, my aims were to:

- determine the group size and age structure of crop-foraging elephants
- identify if spatial and temporal factors influence the group size and age structure of crop-foraging elephants

- determine how elephants move towards and within fields
- identify whether these movement trajectories are influenced by spatial, temporal or crop features

3.3 Methods

3.3.1 Research sessions in the Makgadikgadi Pans National Park

I collected data on a population of free-ranging African elephants from 22nd January 2014 until 9th July 2016 in the MPNP. Four routes were driven on established roads to locate elephants within the national park (Figure 1.1). Upon sighting a group or individual male elephant I recorded: i) the date, time and GPS location, ii) the number of individual bulls in the group, iii) a group size confidence score, iv) the ages of elephants present in the group and v) photographic images of each elephant.

Group sizes of bull elephants can be difficult to determine due to their fluid fission-fusion nature, particularly at resources such as water, where interactions can take place between multiple groups (Moss 1996). Elephants were assumed to be a group if they appeared to be spatially and temporally cohesive, travelling in the same direction, and behaving in a coordinated manner. Sightings were given a group size confidence score: a score of one meant I was confident that all individuals had been seen, two meant it was likely all individuals in the group had been seen but not completely certain, and a score of three meant it was highly likely that not all individuals had been seen.

Elephants were classified into seven age categories, 1-4 years, 5-9 years, 10-15 years, 16-20 years, 21-25 years, 26-35 years and ≥36 years (Moss 1996) (Figure 3.1). Male elephants continue to grow throughout life, making it easier to assign ages based on characteristics of size, physical development, eruption of tusks, the length and circumference of tusks, body shape, head shape and proportions. For example, as an elephant ages, its tusks not only get longer but grow in circumference (Moss 1996). An accurate age could be assigned by using this combination of features. Some sightings could be fleeting or the view of the elephant may have been impaired, meaning it was not possible to age the elephant accurately. These sightings were excluded from the analyses of ages.

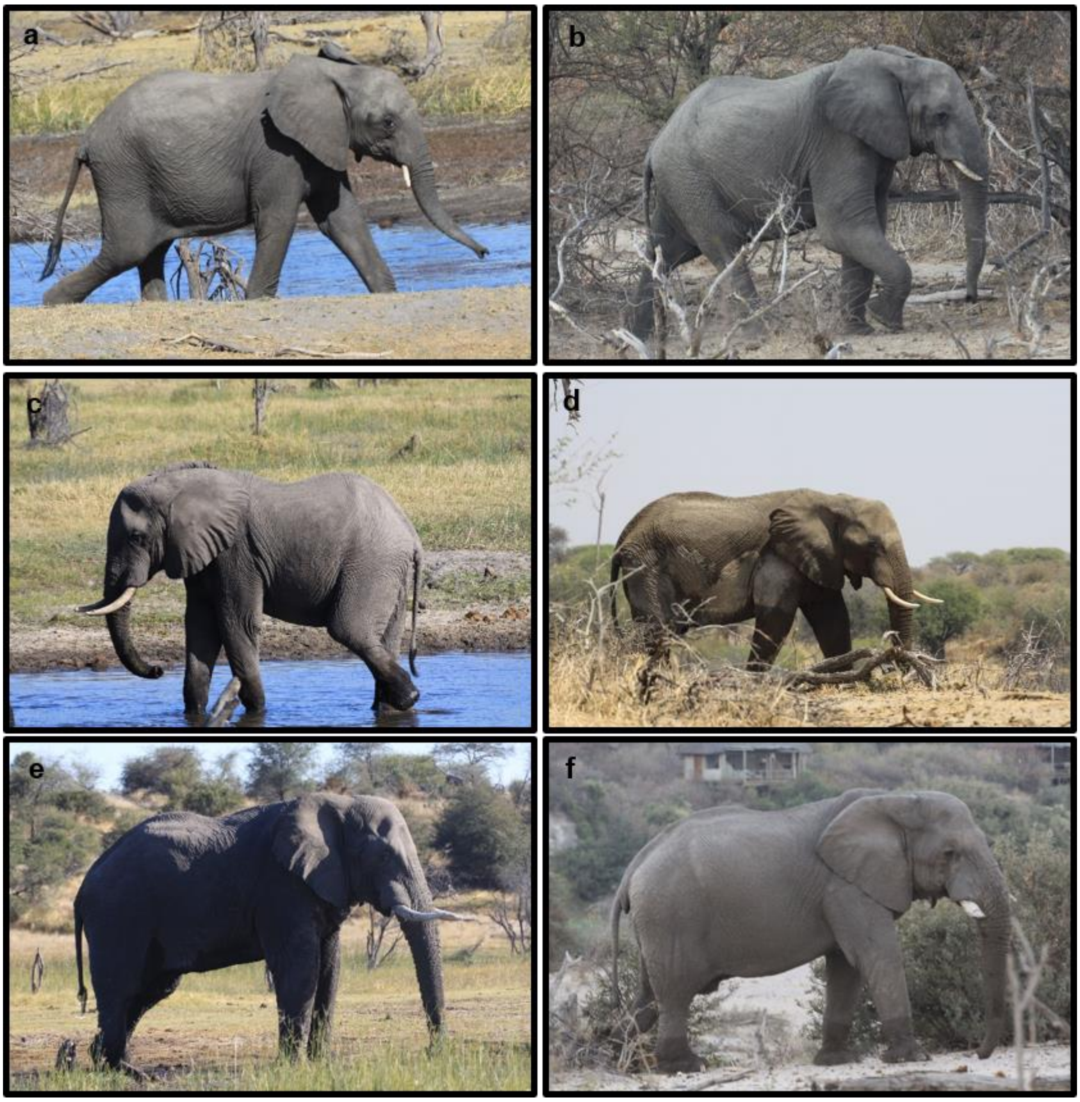

Figure 3.1. Examples of elephants in different age categories a) 5-9 years, b) 10-15 years, c) 16-20 years, d) 21-25 years, e) 26-35 years and f) ≥36 years

Douglas-Hamilton (1972) pioneered a method to identify individual elephants by their ears. Over time, elephants acquire a unique pattern of holes, notches and tears to the edges of their ears (Figure 3.2). The shape of the tusks were also used to identify individuals. Tusks can also become broken and damaged, providing another feature with which to recognise individual elephants, while wounds or lumps on the body offer additional features. So, having determined the group size and age, photographs were taken of both the left and right ear with tusks, a head on view and a side on view of each elephant (Figure 3.3). Feature-based search tools with a Microsoft Access database were then used to identify each elephant.

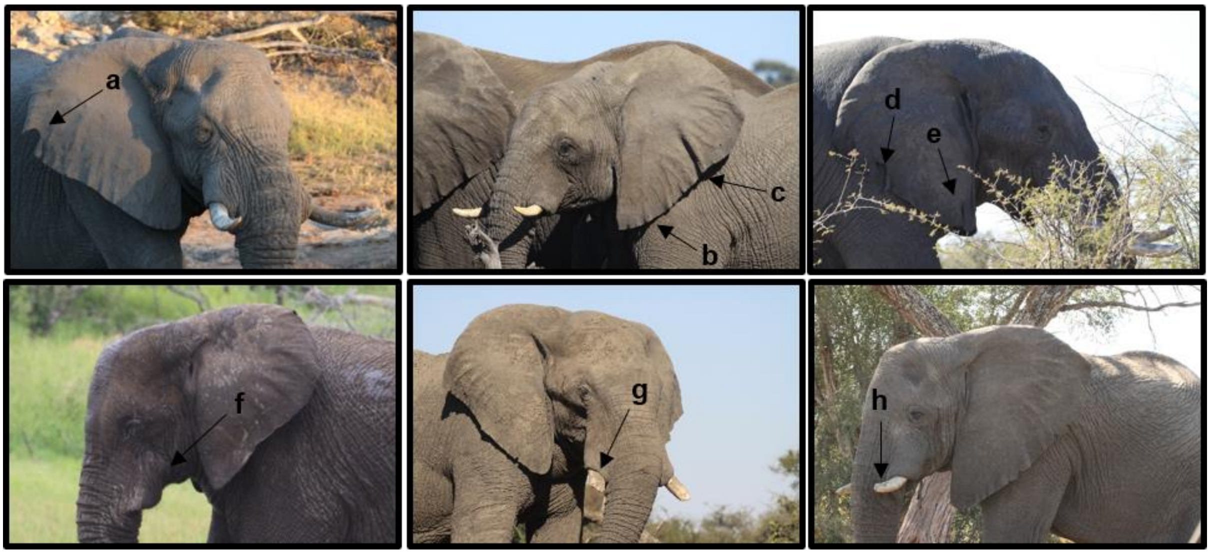

Figure 3.2. Features used to identify elephants a) u-notch, b) small hole, c) dent, d) n-notch, e) slit, f) no tusk, g) broken tusk and h) chiselled tusk

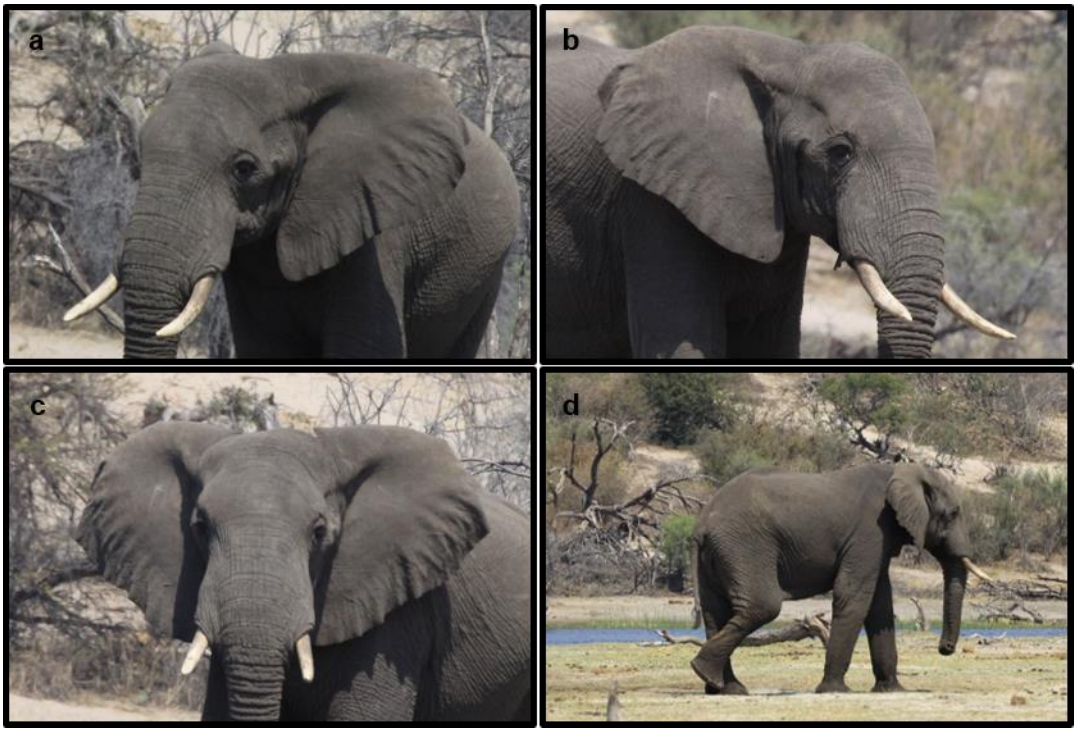

Figure 3.3. A selection of identifying photos collected from a sighting a) left perspective, b) right perspective, c) head on and d) side on body photo of the same elephant

Measurements of hind foot length (HFL) can be used to age elephants (Western, Moss & Georgiadis 1983; Lee & Moss 1986; Moss 1996), although I found that HFLs from east Africa did not match with the estimated ages of elephants in the MPNP. This may have been due to the soft substrate for measurements or spatial differences in the size of elephants. Therefore, I developed a growth curve based on the HFL of African elephants in the MPNP: opportunistic measurements were taken from the hind footprint of male elephants whose age had been estimated. Footprints were measured where they had left a clear impression with a narrow, smooth border around the edge (Figure 3.4). Measurements were taken from the outer, rear edge of the wrinkled area to the back of the toenail using a 1m measuring tape, graduated in cm. Between three and five hind footprints were measured for each animal to the nearest half cm and the average taken. All measurements were required to be within 2cm of each other to ensure high accuracy. In some cases, the footprint may have been disturbed or the clarity reduced due to environmental conditions such as wind, rain or the movement of the elephant. When this occurred, it was necessary to follow the tracks until a clear print could be measured. Identification photos were taken of the elephant whose track was measured when possible to ensure that measurements were not being taken from the same individual on different occasions.

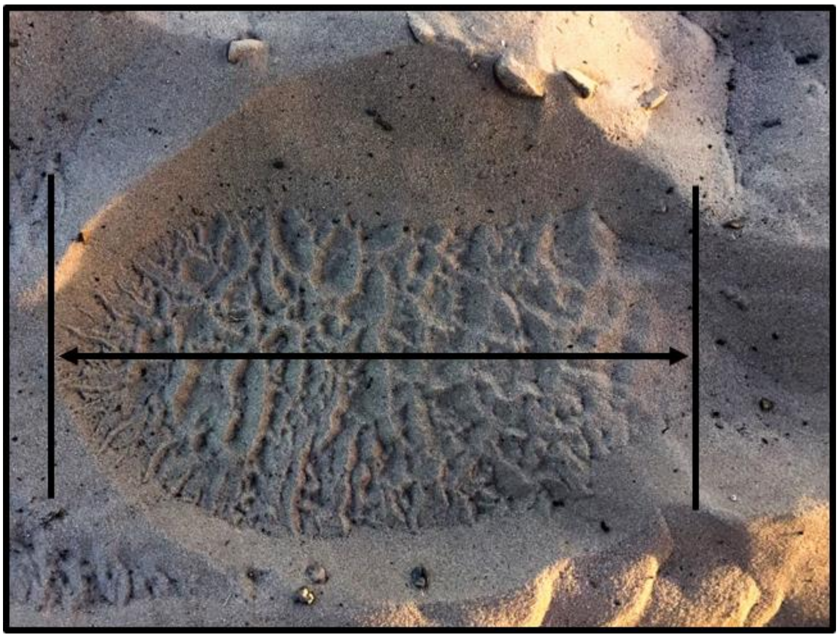

Figure 3.4. African elephant hind footprint with straight lines depicting the rear edge of the foot and back of toenail (from left to right). The arrow depicts where the measurement was taken (photo: Miss Connie Allen)

HFL measurements were collected for the age categories 10-15 years, 16-20 years, 21-25 years, 26-35 years and ≥36 years. It was often possible to determine if the elephant was closer to the lower or upper age boundary. For example, an elephant that was identified as being in the 10-15 years age category but at the lower end of this category was recorded as having an age of 10 years. If it was not possible to determine whether an elephant was in the upper or lower part of the category, it was given the mean age e.g. 12.5 years for an animal in the 10-15 year category. Elephants ≥36 years old were excluded from the growth curve model as it was not possible to determine their upper age.

Previous studies have used the von Bertalanffy equation of the form: $f=L_{\infty}(1-e^{-k(t-t0)})$, where f is the length of the footprint in cm, L_{∞} is the maximum average size of footprints, k is the growth rate constant, t is the age in years and t0 is the theoretical age at which the footprint had zero length (von Bertalanffy 1960; Western, Moss & Georgiadis 1983; Lee & Moss 1986). I used this equation so that I could determine the age of crop-foraging elephants based on their HFL recorded in fields.

3.3.2 Crop-foraging events

I attended crop-foraging events as outlined in section 2.3.1 to determine the group sizes and ages of the elephant(s) involved. It was not possible to confirm the demographics of these elephants visually because crop-foraging occurred mainly at night. Field signs were used to determine the number of elephants that had entered the field and the sex of the individuals. Due to the sexual dimorphism in elephants and the different social structure between males and females, it was possible to tell from field signs whether the elephants were male or female. Females are significantly smaller than males, with the largest female over 40 years only ever reaching the same size as a 17 year male (Lee & Moss 1986; Poole 1996). Also, female breeding herds often include juveniles which can be identified by the presence of small prints. A code was assigned to the data to determine how they were collected i.e. when I identified the tracks, the farmer identified the tracks, I saw the elephant(s) or the farmer saw the elephant(s).

I identified individual tracks of elephants in a field to determine the ages of crop-foraging elephants. Points on the field boundary where elephants had entered provided starting points for identifying these tracks. I then recorded HFL measurements as outlined in section 3.3.1 and converted these to ages (section 3.4.2).

In 2015 and 2016 I tracked the movement trajectories of crop-foraging elephants towards and within fields (Figure 3.5). When attending a crop-foraging event, I identified the elephant(s) entry and exit points to the field. On identifying an entry point I tracked the footprints of individual elephants in the direction they came from using a Garmin GPSmap 62s (Garmin Europe Inc., Southampton, UK) to record its movement pathway towards the field. If possible, tracks were followed for a minimum of 1km. However, some tracks were either degraded by cattle movement or blocked by barriers.

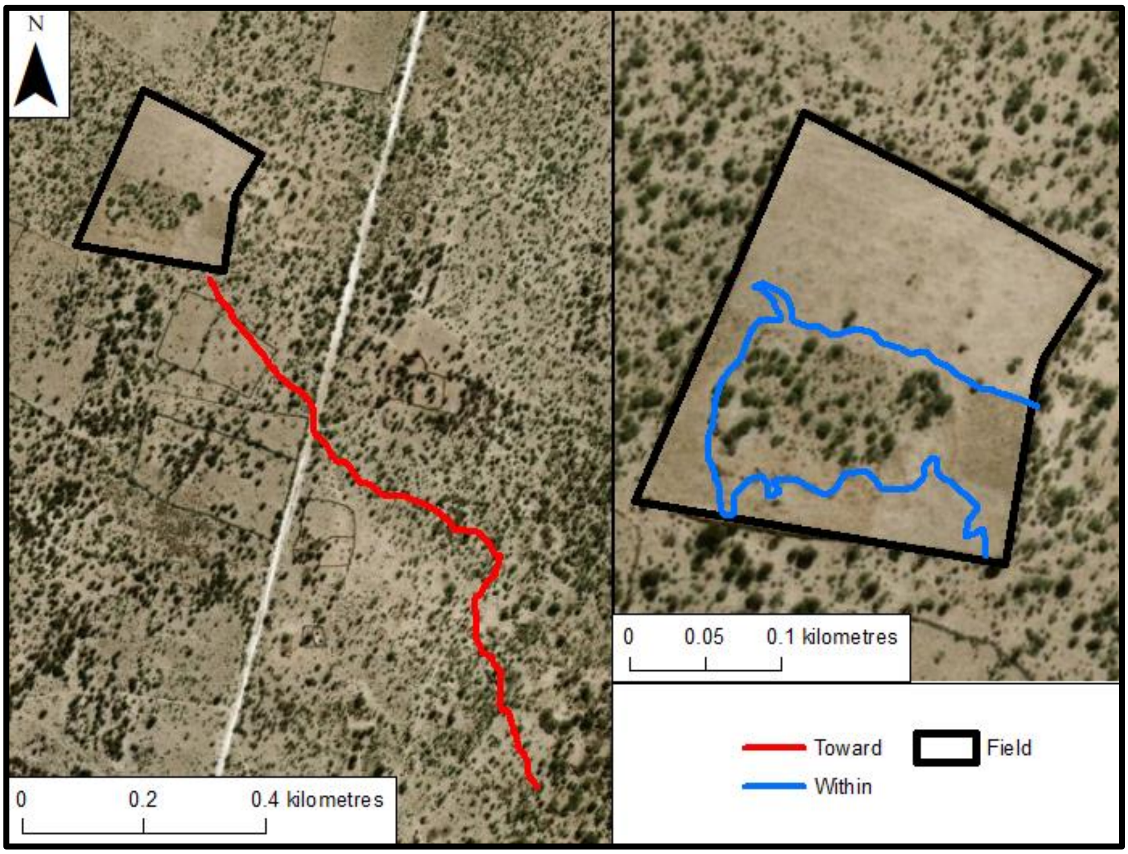

Figure 3.5. Map showing the movement trajectory of an elephant moving towards a field and within it (Layer source: Esri, DigitalGlobe, GeoEye, Earthstar, Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN and the GIS User Community)

The same technique was also used to follow the elephant(s) movements inside the field from the entry point until the elephants exited or it was no longer possible to track. The elephant's movement, entry and exit points into different crop species were recorded using GPS waypoints.

The trajectories of these paths were used to determine the tortuosity of the movement. The fractal dimension (D) of a movement path lies between 1 and 2, with 1 being if the path is straight and 2 being when the path is so tortuous as to completely cover a plane. The tortuosity of a path indicates different movement patterns. For example, a straight path (i.e. less tortuous or lower D) suggests that an animal is only using the area for travel, whereas a more tortuous path (i.e. higher D) suggests the area is receiving increased use (Nams & Bourgeois 2004). The tortuosity of a path can change with spatial scale. For example, at a smaller spatial scale a path may look more or less tortuous than the original path, in which case it is important to calculate fractal D at different spatial scales. However, if fractal D does not change at different spatial scales, it is said to be self-similar or fractal, and fractal D can be estimated over the whole range of spatial scales (Mandelbrot 1967).

To obtain an overall estimate for each movement path I used the Fractal Mean estimator (Nams 2006), which is based on the traditional dividers method (Mandelbrot 1967; Milne 1991). The length of the path is measured by stepping dividers of a certain size along the path. When the length of the path is measured for increasingly larger divider sizes, the slope of log(path length) versus log(divider size) would be 1-D. This would produce an overall estimate for fractal D over a range of scales. While Fractal Mean follows this method, it is different from Mandelbrot (1967) in that it samples the path twice (once forward and once backward). It also corrects for truncation of gross distance (when the dividers reach the beginning/end of the path, but do not reach it exactly) by estimating the extra distance by the straight-line distance between the end of the last divider step and the end of the path. For trajectories towards and within fields I used divider sizes ranging from 5 to 100m with 200 divisions between the minimum and maximum value. The minimum divider size was based on the minimum resolution of the data gathering (Garmin GPSmap 62s), while the higher limit was based on the lengths of the longest paths. For trajectories within different crop types, I used divider sizes ranging from 5 to 20m with 200 divisions between the minimum and maximum value.

3.3.3 Data analysis

To ensure that events in different fields on the same day were independent i.e. not involving the same elephants, I accounted for spatial autocorrelation as described in section 2.3.3. All analysis was performed in R (version 3.3.2).

HFLs of elephants in different age categories were compared using a one-way ANOVA to determine if age influenced HFL.

For analysis of group sizes, I used all the sightings occurring in the MPNP where the group size confidence was either one or two, meaning a high confidence in the group size estimate. I found that the group size of elephants inside the MPNP differed across the year. Therefore, I only used sightings collected between January and May each year in analyses to ensure data were comparable to crop-foraging events. For crop-foraging events, I only used group size data where I had determined the group size either through tracks or visually.

When analysing the ages of elephants, I used all sightings inside the MPNP where the group size confidence was either one or two and where all the elephants in the sighting were successfully aged. I then coded the presence and absence of all the age categories for each sighting. If multiple elephants in the same sighting were the same age, I duplicated the presence of that age category for that sighting. For crop-foraging events, I only used those in which ages of all elephants involved in the event could be determined. I then coded the presence and absence of each age category in the same way as sightings inside the MPNP.

To investigate whether the group size of African elephants differed between elephants seen in the MPNP and those foraging on crops in communal lands, and whether factors (distance from the MPNP; distance to nearest field; month) influenced group sizes of elephants foraging on crops, group size data were analysed with lognormal generalised linear mixed models (GLMMs) with “field/sighting ID” nested within “year”, using the package “lme4” (Bates *et al.* 2015) (Table 3.1(Models 1-3)).

Binomial GLMMs were used to investigate whether the location of a group of elephants (MPNP or communal lands) influenced the presence or absence of certain age categories, and which factors (distance from the MPNP; month) might influence the ages of elephants involved in crop-foraging events. The “group ID” was nested within “field/sighting ID”, which was nested within “year” to account for non-independence (Table 3.1 (Models 4-6)).

Table 3.1. Full generalised linear mixed models used for data analysis outlining the fixed and random effects, and model family used

Model	Data set	Response	Fixed effect	Random effect	Model family
1	MPNP and crop-foraging events	group size	location; month; location x month	year*field/sighting ID	lognormal (Gaussian with $\log_{10}$+1 transformed response variable)
2	Crop-foraging events	group size	distance to the MPNP; distance to nearest field	year*field ID	lognormal (Gaussian with $\log_{10}$+1 transformed response variable)
3	Crop-foraging events	group size	distance to the MPNP; month; distance to the MPNP x month	year*field ID	lognormal (Gaussian with $\log_{10}$+1 transformed response variable)
4	MPNP and crop-foraging events	presence of age category (yes/no)	location; age category; location x age category	year*field/sighting ID*group ID	binomial (link=probit)
5	Crop-foraging events	presence of age category (yes/no)	distance to the MPNP; age category; distance to the MPNP x age category	year*field ID*group ID	binomial (link=cauchit)
6	Crop-foraging events	presence of age category (yes/no)	month; age category; month x age category	year*field ID*group ID	binomial (link=logit)

For statistical analyses using fractal D, D was not normally distributed. I therefore transformed D following $\log_{10}(D-1)$, resulting in a normal distribution, allowing parametric tests. Fractal D scores were only used for trajectories towards and within fields when there was a minimum of 10 steps for each trajectory, whereas trajectories in different crop types required a minimum of five steps to be included in the analysis.

Fractal D scores were calculated for trajectories towards fields and within them. To determine if there were differences in the tortuosity of movement trajectories, the fractal D scores for each trajectory were compared using a two-sample t-test. To determine if movement trajectories changed as the crop season progressed, a Pearson product moment correlation was performed to see if there was a correlation between fractal D scores and the number of days since 1st January for both trajectories towards and within fields. A one-way ANOVA was performed to see if month influenced the fractal D scores of trajectories within fields. There were not enough trajectories to perform this analysis for trajectories towards fields. Fractal D scores for trajectories within different crop types were compared using a one-way ANOVA to determine if the crop the elephant was moving through influenced tortuosity of movement trajectories.

3.4 Results

3.4.1 Research sessions inside the MPNP

In total, 241 research sessions inside the MPNP were completed during the three-year study, resulting in 1084 individual or group sightings of male elephants. On average, there were 4.5 (range 0-21, SD 4.1) individual or group sightings of male elephants on each research session. Each sighting lasted on average 10.0mins (range 0-103, SD 12.4). The average time for a research session was 4.1hrs (range 1.0-9.2, SD 1.0) and the average distance travelled 50.6km (range 13-124, SD 15.4) (Table S3.1).

The average group size of elephants sighted was 2.6 individuals (range 1-17, SD 2.3). Of the 1084 individual or group sightings of male elephants, 853 had a group size confidence of one or two, indicating a high confidence in group size certainty. The average group size of elephants sighted from this subset was 2.5 individuals (range 1-16, SD 2.2); 46.8% of sightings were of lone bulls (Figure S3.1).

From the 853 group sightings with high confidence of group sizes, there were 605 group sightings where all individuals (1225 males) were successfully aged. The most frequently observed age category was 16-20 years, followed by 21-25 years, 26-35 years, 10-15 years, ≥36 years, 5-9 years and 1-4 years (Figure 3.6).

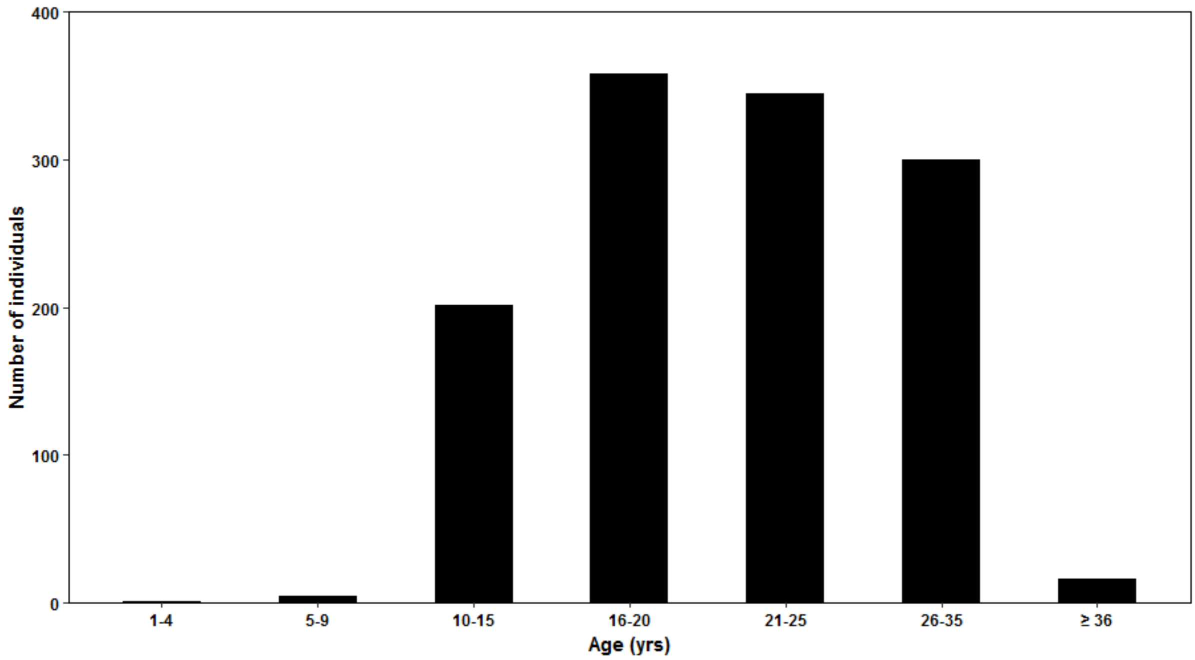

Figure 3.6. The ages of 1225 male African elephants observed in the MPNP, Botswana between January 2014 and July 2016

3.4.2 Hind foot length model

I collected hind foot length measurements (HFL) for 134 aged elephants. The age of the elephant significantly influenced its HFL length (one-way ANOVA: $F_{4,129}$=98.950, P<0.001) (Figure 3.7). A Tukey HSD *post hoc* test revealed significant differences in mean HFL between all age classes except 26-35 years and ≥36 years (Table S3.2).

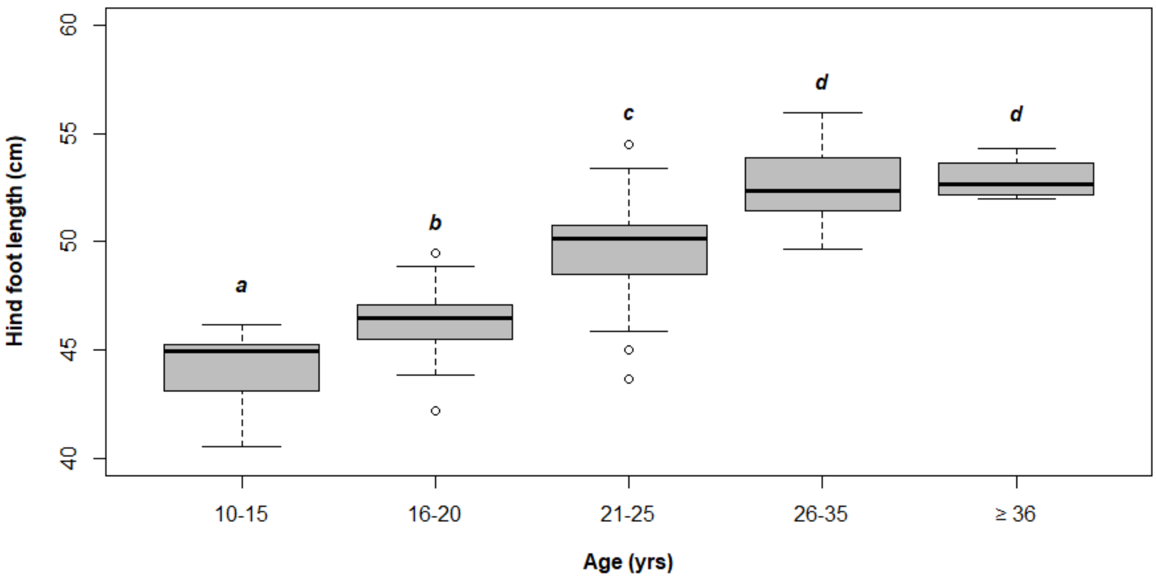

Figure 3.7. The hind foot lengths (cm) for 134 male African elephants categorised by age. Box plots show the median, 25th and 75th percentiles, whiskers indicate values within 1.5 times the interquartile range from these percentiles, and circles indicate values greater than 1.5 times the interquartile range. Different italicised letters indicate significant differences identified by *post hoc* comparisons

A growth curve was fitted to measurements of HFL. The best fit equation developed was $f=58.9(1-e^{-0.05(t--12.95)})$ (Figure 3.8). Having produced a growth curve for HFL based on age, it was then possible to calculate predicted hind foot length for all the age categories based on entering upper and lower ages for each age category into the equation and recording the estimated HFL (Table S3.3).

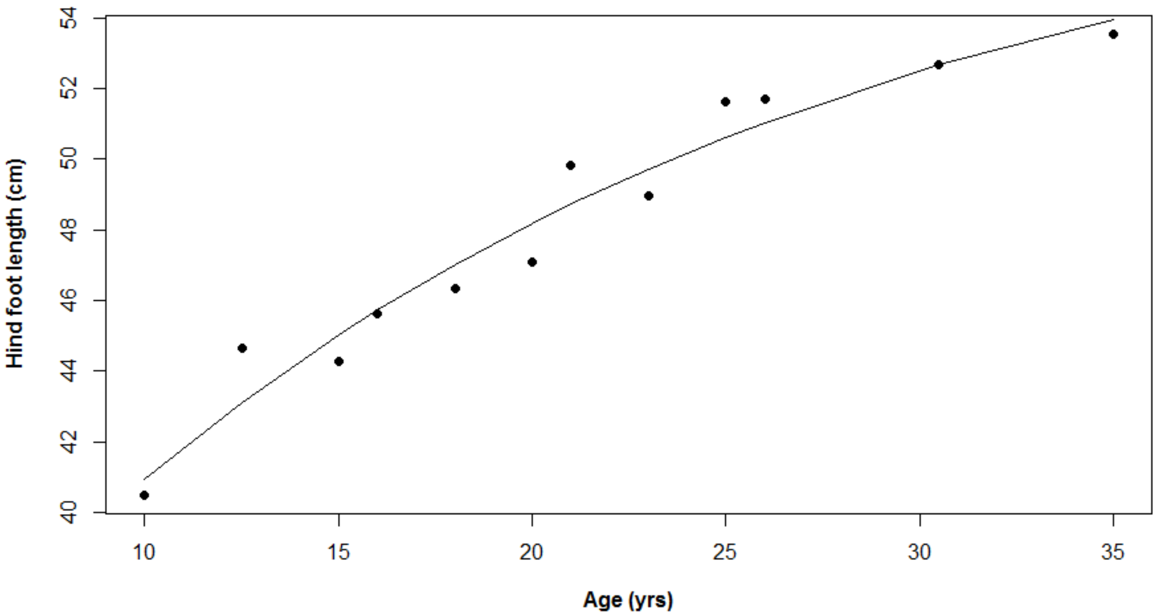

Figure 3.8. Growth curve of average hind foot length with age for male African elephants in the MPNP, Botswana

3.4.3 Characteristics of crop-foraging events

I attended 375 crop-foraging events over three years with all but two events involving male elephants. The group size of crop-foraging elephants was determined on 172 occasions. When accounting for spatial autocorrelation in the dataset (section 2.3.3), 129/172 crop-foraging events were not influenced by spatial autocorrelation. For these, average group size was 2.4 elephants (range 1-8, SD 1.5) (Figure 3.9).

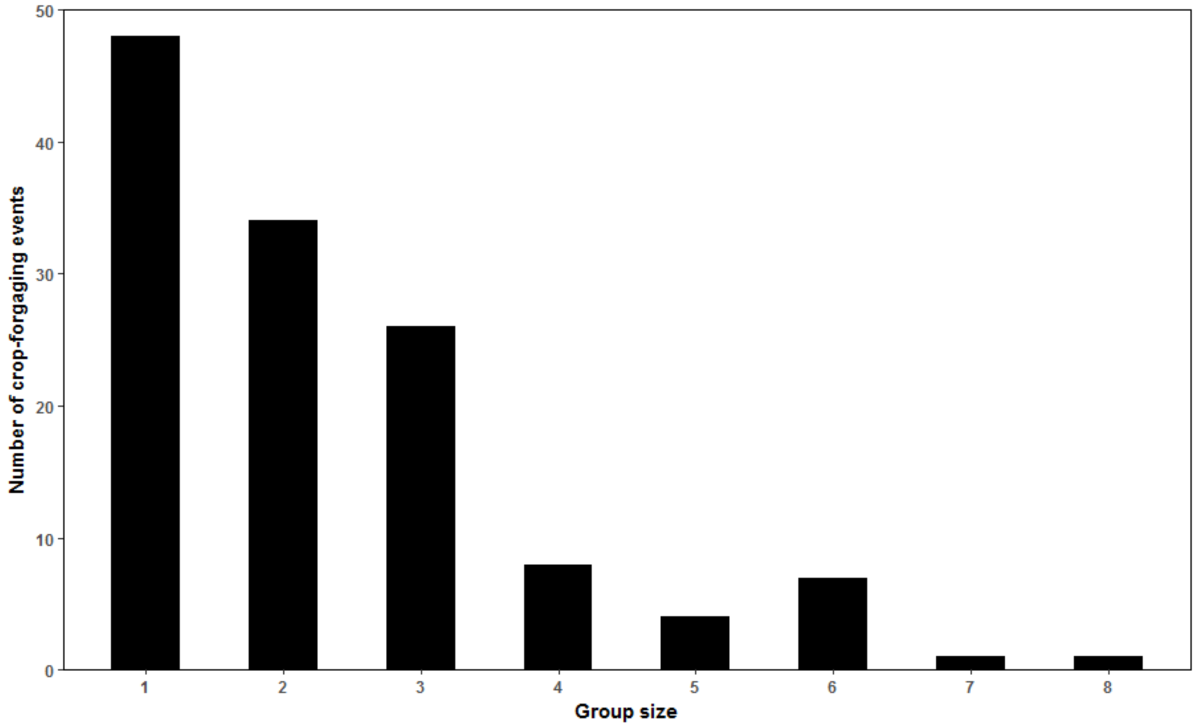

Figure 3.9. The sizes of 129 male African elephant groups crop-foraging in the Makgadikgadi region, Botswana, between February 2014 and May 2016

Having accounted for spatial autocorrelation, there were 68 crop-foraging events where the ages of all crop-foraging individuals (n=120) were determined. Elephants in the 26-35 year age category were most prevalent followed by 21-25 years, ≥36 years, 16-20 years, 10-15 years and finally elephants that were less than 10 years of age (Figure 3.10).

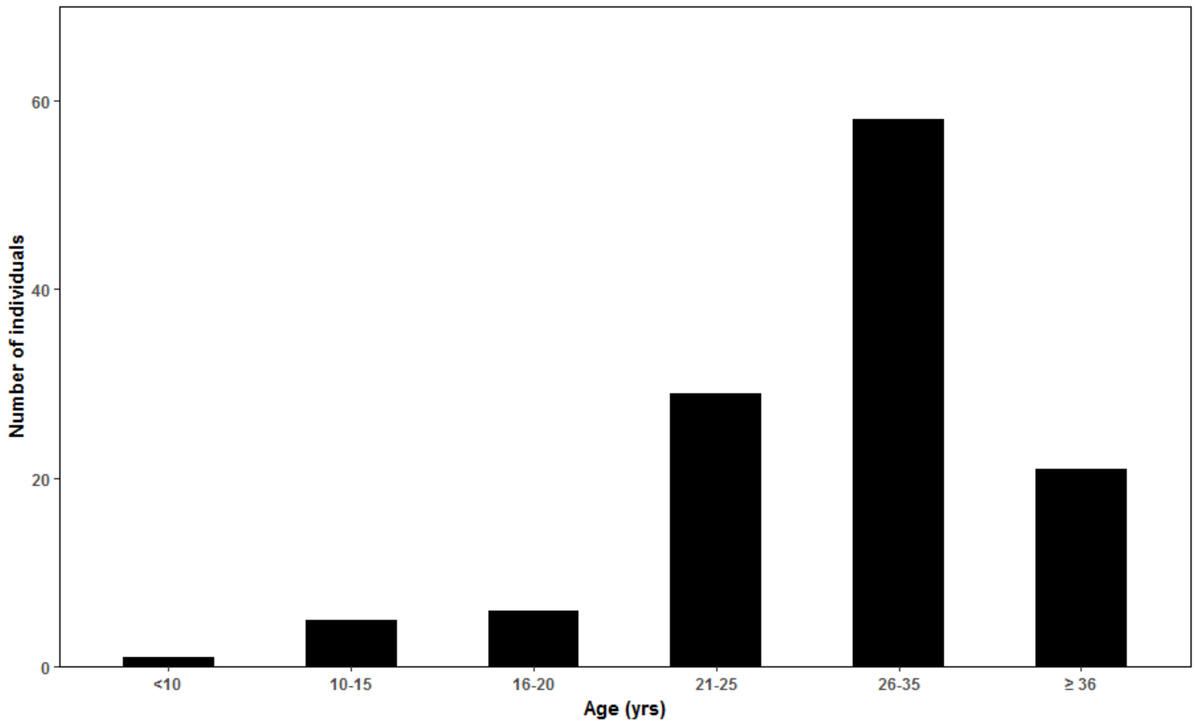

Figure 3.10. The ages of 120 male African elephants crop-foraging in the Makgadikgadi region, Botswana, between February 2014 and May 2016

A total of 51 movement paths were recorded from 39 elephants, during 32 crop-foraging events, covering 27.8km. Fifteen tracks, covering 15.9km, had trajectories towards fields, and 36 tracks, covering 11.9km, were inside fields. The average recorded path length for trajectories towards fields was 1.1km (range 0.3-2.6, SD 0.6), with an average of 151 GPS locations (range 41-339, SD 72.8), while trajectories within fields had an average path length of 0.4km (range <0.1-1.2, SD 0.3) and an average of 67 GPS locations (range 5-200, SD 51.3).

Trajectories recorded inside fields were split into 127 sections based on the crop type the elephant was moving through. Fractal D scores were calculated for 68 of these trajectories. Movement paths were recorded in six different crop types (cowpeas, maize, millet, sorghum, sweet reed and watermelon) (Table S3.4).

3.4.4 Demographics of elephants involved in crop-foraging events and factors influencing them

Neither location nor month had a significant effect, either alone or in combination, in influencing the group size of male elephants. However, the interaction between the two did have an effect (Table 3.2). Although there was no difference in group sizes between crop-foraging elephants and those in the MPNP, in May the group sizes of crop-foraging elephants were significantly larger than group sizes inside the MPNP (Figure 3.11).

Table 3.2. Results of a Gaussian GLMM investigating the effect of location and month on the group size of male African elephants. Significant *P*-values for fixed effects included in the minimal model are shown in bold. Sample size=601 events (an event was defined as a crop-foraging event or an elephant sighting in the MPNP)

Model parameter	**β**	**SE**	**t**	χ^2	**df**	***P***
Fixed effects						
Intercept	-0.107	0.125	-0.852			
Location * Month				32.034	9	**<0.001**
Location(MPNP):Month(February)	-0.212	0.140	-1.518			
Location(MPNP):Month(March)	-0.465	0.140	-3.318			
Location(MPNP):Month(April)	-0.419	0.143	-2.938			
Location(MPNP):Month(May)	-0.718	0.166	-4.320			
Random effects	Variance	SD				
Field/sighting ID:Year(N=533)	0.043	0.207				
Year (N=3)	<0.001	0.014				

Reference categories were Location=Field and Month=January

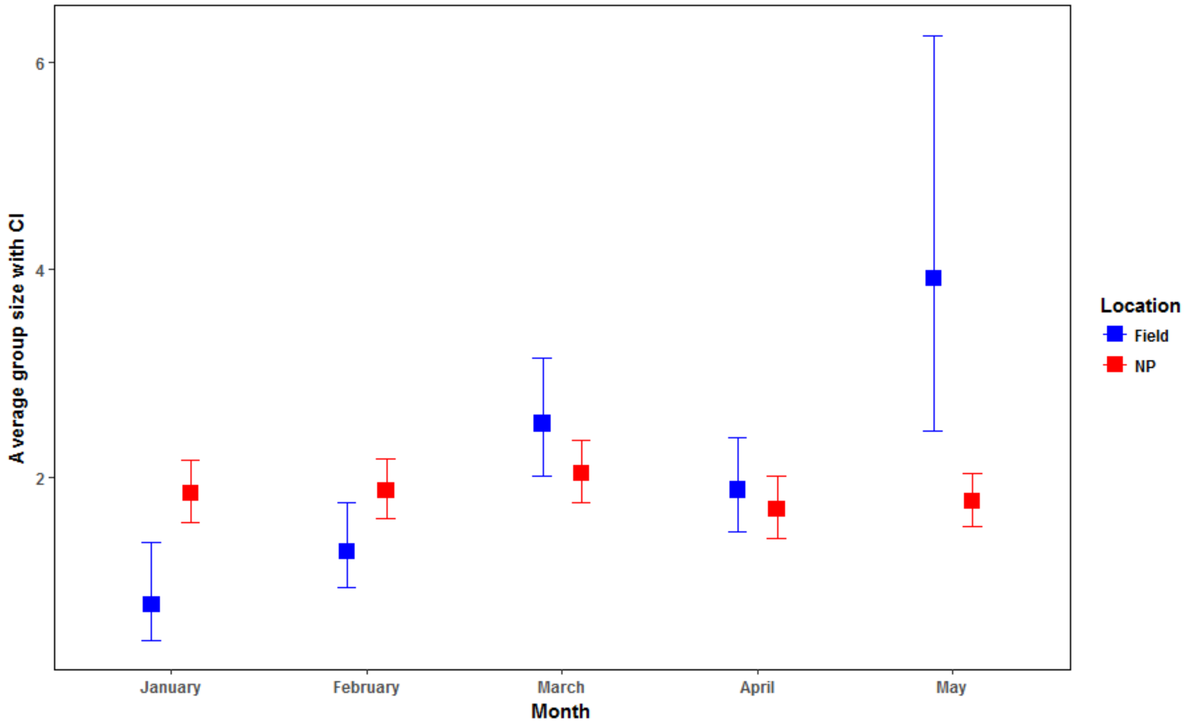

Figure 3.11. The average group size of male African elephants located in fields (blue) and the MPNP (red) categorised by month

Distance to the nearest field had no significant effect on group size, either in combination with distance from the MPNP (remove distance to nearest field from full model: Δdeviance=1.218, d.f.=1, *P*=0.270) or by itself (distance to nearest field model compared to null model: Δdeviance=1.171, d.f.=1, *P*=0.279). However, the distance from the MPNP did influence the group size, with group size increasing as distance from the MPNP increased (distance from the MPNP model compared to null model: Δdeviance=7.885, d.f.=1, *P*=0.005). However, the model only explained 6.0% of the variation in group size, and so the effect size was small.

When including month and distance from the MPNP as fixed effects and an interaction effect between the two, the interaction was found to be significant (Table 3.3). In all months except February, the group sizes of crop-foraging elephants increased in fields further from the MPNP (Figure 3.12). *Post hoc* pairwise comparisons using Tukey HSD identified that the slopes of distance from the MPNP against group size were not significantly different between months, except for the slopes of February and March (Table S3.5).

Table 3.3. Results of a Gaussian GLMM investigating the effect of distance from field to the MPNP and month on the group size of crop-foraging elephants. Significant *P*-values for fixed effects included in the minimal model are shown in bold. Sample size=129 crop-foraging events

Model parameter	**β**	**SE**	**t**	x^2	**df**	***P***
Fixed effects						
Intercept	-0.035	0.116	-0.301			
Dist. to MPNP * Month				51.736	9	**<0.001**
Dist. to MPNP:Month(February)	-0.208	0.142	-1.463			
Dist. to MPNP:Month(March)	0.125	0.134	0.934			
Dist. to MPNP:Month(April)	0.031	0.143	0.215			
Dist. to MPNP:Month(May)	-0.015	0.186	-0.082			
Random effects	Variance	SD				
Field ID:Year(N=61)	0.010	0.101				
Year (N=3)	0.0	0.0				

Reference categories were Month=January

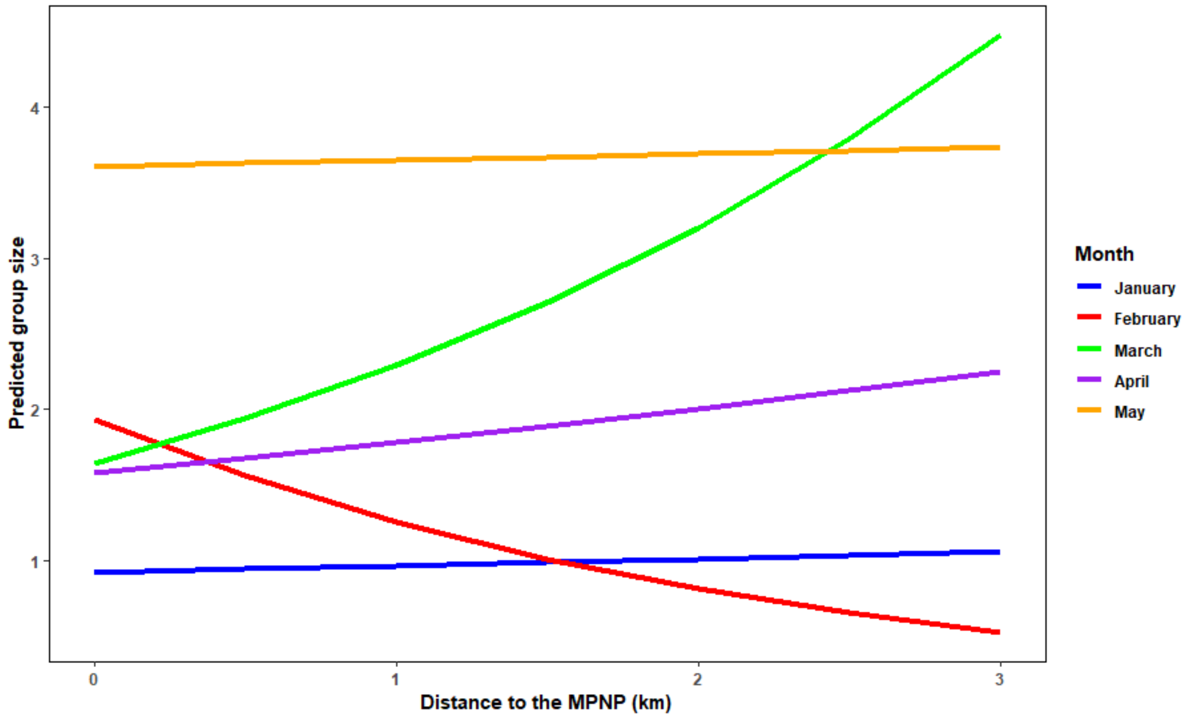

Figure 3.12. The predicted group size of crop-foraging elephants at different distances to the MPNP recorded for different months

An interaction was observed between the age of an elephant and the location where it was observed when predicting its presence or absence (model with interaction compared to model without: Δdeviance=143.590, d.f.=5, P<0.001) (Table 3.4). Elephants in the 26-35 years age category had the highest probability of being present during a crop-foraging event, followed by elephants 21-25 years and ≥36 years old. Elephants <20 years old were least likely to be present during a crop-foraging event. Inside the MPNP, elephants 21-25 years, 16-20 years and 26-35 years old had the highest probability of being observed, followed by 10-15 years, and elephants ≥36 years and <10 years old. When comparing ages of elephants involved in crop-foraging events in fields and those in the MPNP, there was a significantly higher probability of elephants 26-35 years and ≥36 years old being present in fields and a significantly lower probability of elephants 10-15 years and 16-20 years old. There was no difference in probability for elephants that were <10 years and 21-25 years old (Figure 3.13).

Table 3.4. Results of a binomial GLMM investigating the effect of age and location on the presence and absence of age categories. Significant *P*-values for fixed effects included in the minimal model are shown in bold. Sample size=673 events (605 sightings in the MPNP and 68 crop-foraging events)

Model parameter	**β**	**SE**	**z**	χ^2	**df**	***P***
Fixed effects						
Intercept	-2.207	0.397	-5.559			
Age * Location				722.430	11	**<0.001**
Location(MPNP):Age(10-15)	1.014	0.495	2.049			
Location(MPNP):Age(16-20)	1.375	0.490	2.809			
Location(MPNP):Age(21-25)	0.295	0.463	0.637			
Location(MPNP):Age(26-35)	-0.741	0.463	-1.598			
Location(MPNP):Age(≥36)	-1.513	0.487	-3.107			
Random effects	Variance	SD				
Group ID:Field/sighting ID:Year (N=425)	<0.001	0.002				
Field:Year(N=391)	0.034	0.185				
Year (N=3)	<0.001	0.001				

Reference categories were Location=Field and Age=<10

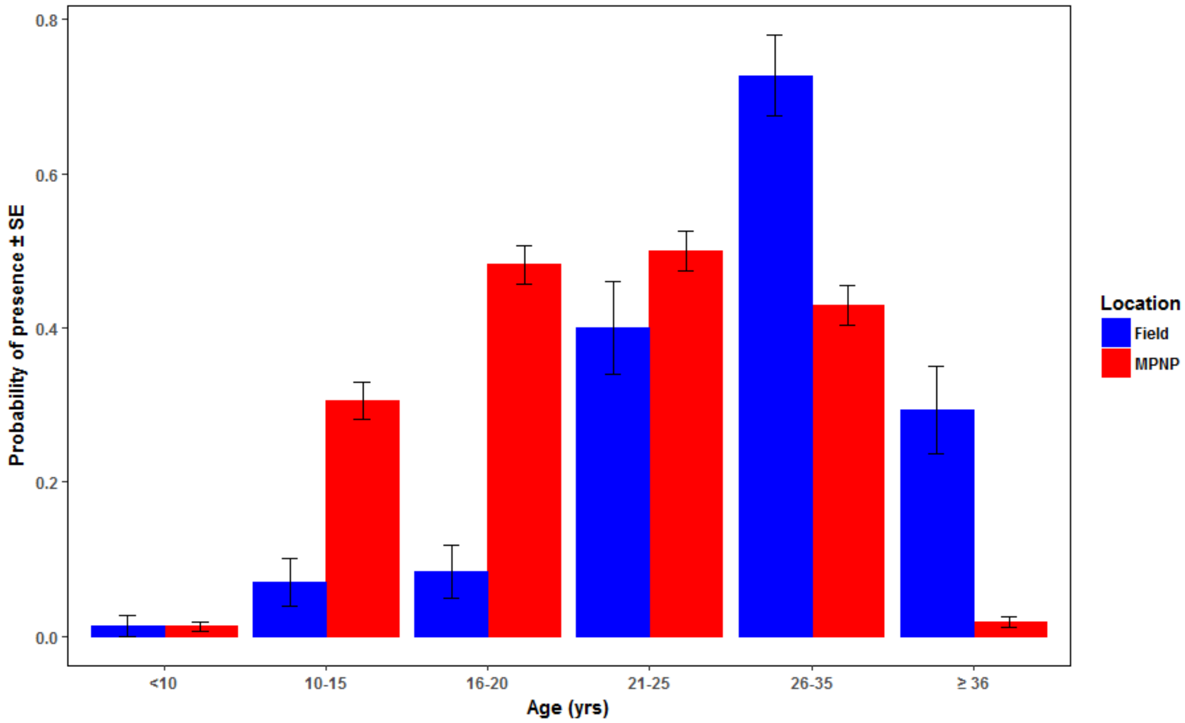

Figure 3.13. The probability of male African elephants of different ages being recorded in fields or observed in the MPNP

There was no interaction between the age of crop-foraging elephants and month (model with interaction compared to model without: Δdeviance=26.435, d.f.=20, *P*=0.152). Likewise, there was no interaction between the age of crop-foraging elephants and the distance from the MPNP (model with interaction compared to model without: Δdeviance=10.430, d.f.=5, *P*=0.064).

3.4.5 Movement trajectories

Males move more directly towards a field than when within a field. Movement trajectories towards fields had a significantly smaller fractal D in comparison to trajectories within fields (two sample t-test: t_{47}=6.503, *P*<0.001), suggesting that trajectories within fields were more tortuous than those towards fields (Figure 3.14).

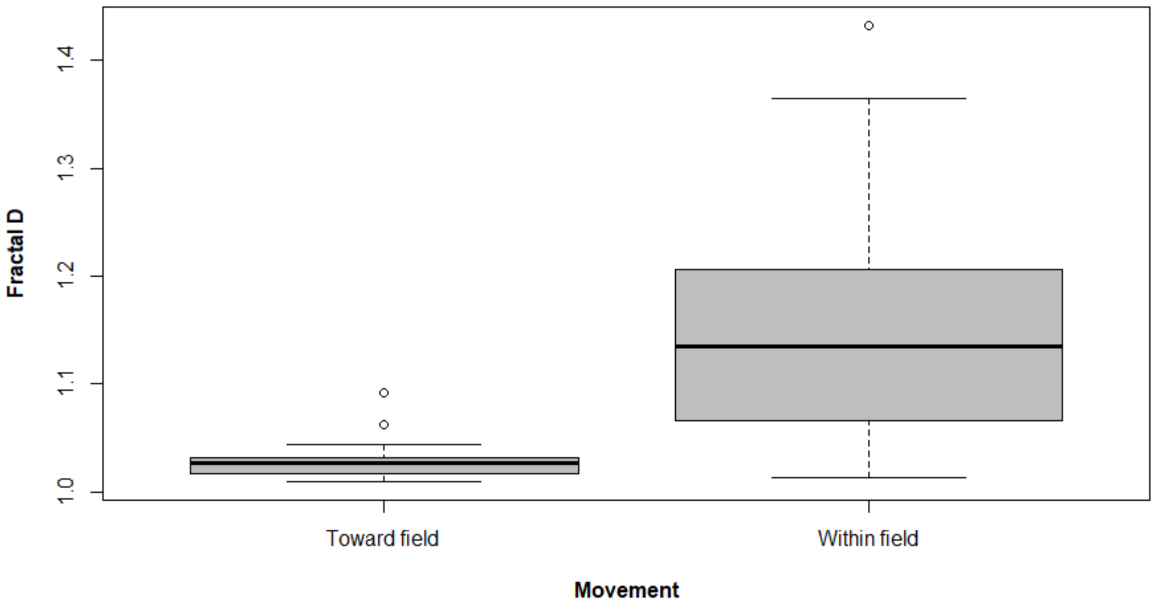

Figure 3.14. The fractal D scores for movement trajectories of male African elephants moving towards (n=15) and within fields (n=36). The fractal D score lies between 1 and 2. It is 1 if the path is straight and a maximum of 2 when the path is so tortuous it completely covers a plane

There was no correlation between the fractal D scores and date for trajectories moving towards fields (Pearson's product moment correlation: r=0.208, d.f.= 13, P=0.457) or within them (Pearson's product moment correlation: r=0.210, d.f.=32, P=0.233). Nor were the fractal D scores of trajectories within fields influenced by month (one-way ANOVA: $F_{3,30}$=0.877, P=0.464). Crop type did not influence how elephants moved inside fields (one-way ANOVA: $F_{4,63}$=2.331, P=0.065) (Figure 3.15).

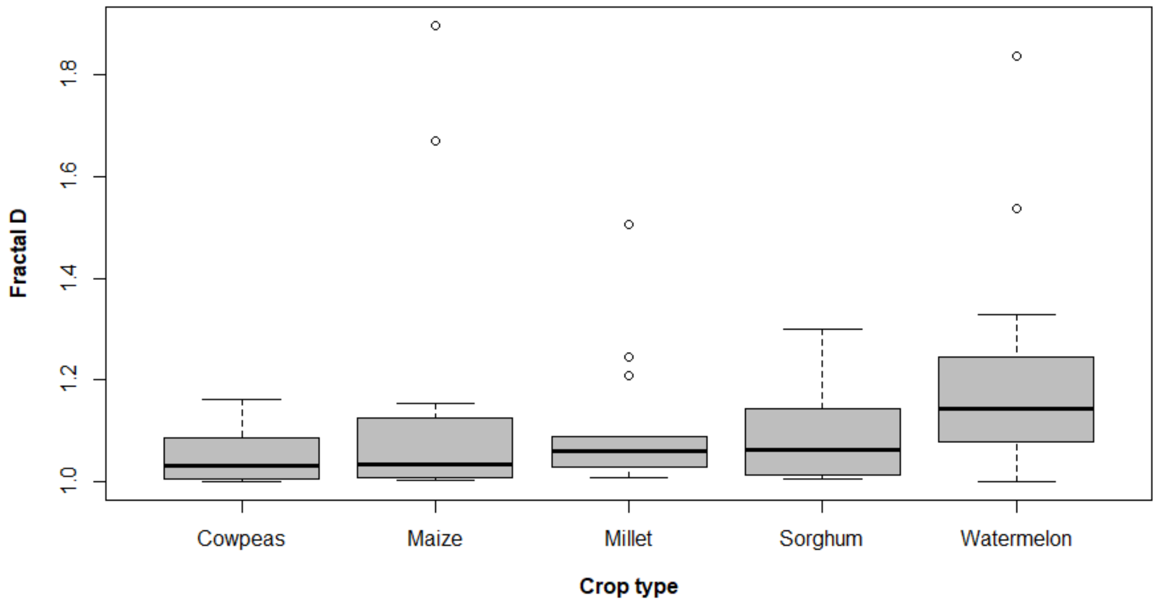

Figure 3.15. The fractal D scores for movement trajectories of male African elephants moving within different crop types (n=68). The fractal D score lies between 1 and 2, with 1 indicating a straight path and 2 indicating when the path is so tortuous that it completely covers a plane

3.5 Discussion

The group sizes of male African elephants did not differ between those observed in the MPNP and those foraging on crops in communal lands. However, fields that were further from the MPNP were entered by larger groups of elephants and elephants >26 years old had a higher probability of being present during a crop-foraging event, although the ages of elephants foraging on crops were not influenced by spatial or temporal factors. Elephants showed directed movement towards fields. However, once inside, tortuosity increased, although intensive foraging in specific crops was not observed.

3.5.1 Crop-foraging: high-gain but not high-risk in the Makgadikgadi region

Foraging on crops is considered a high-risk, high-gain foraging strategy (Chiyo *et al.* 2011b), with the risk of injury or death (Obanda *et al.* 2008) being offset by the gains of highly nutritious foods in comparison to natural forage (Sukumar & Gadgil 1988; Sukumar 1990), with better palatability and higher levels of essential minerals (Rode *et al.* 2006). The demographics of elephants foraging on crops may differ from groups inside a protected area in response to increased risk and detection, and so elephants within certain demographics may have increased probability of crop-foraging due to the potential high gains. Studying male elephants that live in a fission-fusion society provides an opportunity to see how these group dynamics might be influenced in both space and time (Wittemyer, Douglas-Hamilton & Getz 2005; Archie, Moss & Alberts 2006; Chiyo *et al.* 2011a).

While group sizes did not appear to be influenced by the high-risk behaviour of crop-foraging, the age structure within groups was influenced by the potential high gains. Crop-foraging events disproportionately involve older male elephants (Hoare 1999a; Nyhus, Tilson & Sumianto 2000; Williams, Johnsingh & Krausman 2001; Jackson *et al.* 2008; Ahlering *et al.* 2011; Chiyo *et al.* 2011c; von Gerhardt *et al.* 2014; Smit *et al.* 2017). Chiyo, Moss & Alberts (2012) found that the probability of crop-foraging by male elephants increased as a function of age. The shift towards increased probability of an age category being involved in crop-foraging occurs when male elephants start to compete for mating opportunities (Poole 1989; Hollister-Smith *et al.* 2007). Crop-foraging provides elephants with an increased energy payoff, by maximising foraging efficiency, through reduced time spent, and distance travelled, while foraging. The propensity of crop-foraging was found to predict male size in adulthood, with crop-foragers being larger than elephants that did not forage on crops (Chiyo *et al.* 2011b). This male dominated strategy has been observed for other species in a human-dominated landscape (Strum 1994; Saj, Sicotte & Paterson 1999; Odden *et al.* 2002; Wilson, Hauser & Wrangham 2007). Male buffalo *Syncerus caffer* foraged in higher predation risk areas for additional energy gains (Hay, Cross & Funston 2008). My results support the hypothesis that this high-gain foraging strategy occurs at the onset of reproduction and explains why older male elephants are involved in a higher proportion of crop-foraging events, having accounted for the overall population.

Elephants modify their behaviour in human-dominated landscapes in relation to perceived threat (Douglas-Hamilton, Krink & Vollrath 2005; Graham *et al.* 2009a; Gunn *et al.* 2014). Male Asian elephants formed larger groups during crop-foraging, with solitary bull sightings occurring more frequently in forests than crop-foraging events (Sukumar & Gadgil 1988). Increased group sizes have been observed for other species in response to increased mortality risk (Hill & Lee 1998). Chimpanzees *Pan troglodytes* travel in larger parties when visiting crops (Wilson, Hauser & Wrangham 2007). It might also be conceivable that group sizes would be smaller than expected to avoid detection. Primates foraging on crops in smaller groups had a lower probability of being detected (Wallace & Hill 2012). In north-western India, female Asian elephants entered fields in smaller groups, although this was attributed to the reluctance of females with young calves to accompany the herd into higher risk activities (Williams, Johnsingh & Krausman 2001). Although it might have been expected that the group sizes of elephants foraging on crops would differ from those inside a protected area in response to increased risk and detection, this was not the case.

Furthermore, while group size in communal lands was influenced by the distance to the protected area, the small effect size resulted in limited biological significance. Farmers in the Makgadikgadi region do not actively guard their fields. Of 143 farmers interviewed (chapter 4), only 17 (11.8%) reported mitigation strategies that involved actively guarding their fields. Therefore, beyond moving through human-dominated areas at night, the elephants' perceived risk may not be high enough to result in changes in group size. In regions where guarding does take place and elephants come into direct contact with farmers, the risk of injury or death is increased, potentially resulting in changes in group size. Future research in areas where perceived risk could be higher might identify if elephants modify group size.

The availability of resources influences group sizes: smaller group sizes often occur when resources are scarcer (Chiyo *et al.* 2014). When resources are abundant in fields, it might be expected that group sizes would increase as there is reduced competition. Asian bull elephants aggregated during the finger millet season when crops were abundant (Sukumar & Gadgil 1988). Spatial differences in group size did not occur except when group sizes of crop-foraging elephants increased closer to the MPNP in February in contrast to the pattern for other months. This was possibly due to crops in molapo fields maturing earlier on the boundary of the MPNP, therefore resulting in an abundance of mature crops and increased group sizes. It was also hypothesised that temporal changes in crop maturity may result in increased group sizes and probability of older elephants being present. Although group sizes were significantly bigger in fields compared to the MPNP in May, the small number of crop-foraging events occurring in May could have caused this difference. Fields in the Makgadikgadi region were not homogenous. The time taken for different crops to reach maturity varied, as did the commencement of farming practices (chapter 4). This caused high variation in crop maturity within and between fields during the season (personal observation). Identifying the effect of crop maturity on group sizes and ages would therefore be difficult.

3.5.2 Direct movement towards fields, intensive foraging within

Optimal foraging strategy predicts that an animal should gain the most benefit for the lowest cost (Krebs & Davies 1991). By minimizing travel distance, elephants are optimising their foraging ability. African elephant cow herds moved more directly between food patches than within them (Dai *et al.* 2007). Elephants use well-trodden linear pathways and directed movement to reach fruit trees, minerals and water sources (Blake & Inkamba-Nkulu 2004; Shannon *et al.* 2009; Duffy *et al.* 2011; von Gerhardt *et al.* 2014). In the Makgadikgadi region, elephants on the western side of the MPNP leave the “safety” of the protected area, moving into a human-dominated landscape to forage on crops. As foraging on crops is seasonal (chapter 2), there were no well-trodden pathways (personal observation). Yet male movement trajectories towards fields were direct, suggesting fields were targeted. Elephants have demonstrated very precise spatial memory when accessing water resources (Polansky, Kilian & Wittemyer 2015). Elephants might be utilising their spatial memory when travelling towards fields.

When present in a high-quality habitat such as a field, it would be expected that foraging would be intensive, characterised by low travel speeds and high trajectory sinuosity (von Gerhardt *et al.* 2014). The high tortuosity of movement within crop fields is likely to be a result of intensive foraging. Once inside a field, with an abundance of food sources, there would be few factors that would cause an elephant to move on unless detected by humans.

Foraging more intensively in one type of crop might suggest selection. Crop fields in the study were not homogenous, with an average field containing 4.8 different crop types (chapter 2). Although movements in sections of watermelons appeared to show greater tortuosity, this difference was not significant. Elephants are generalist foragers, with dietary generalism expected to increase with increasing body size in mammalian herbivores (Owen-Smith 1988). It might be expected that male elephants are less selective than females when foraging due to their greater size (Stokke & du Toit 2000; Shannon *et al.* 2006). The propensity for male elephants involved in crop-foraging in the Makgadikgadi region may explain why no difference in movement trajectories were observed between different crops.

Future research might investigate how elephants target fields. In areas where elephants are using pathways to travel from one resource to another but diverge off these pathways to forage on crops, it might be hypothesised that elephants use olfaction. Olfaction might be used in the

Makgadikgadi region. However, the observation of one elephant passing through four unploughed fields before reaching a field with crops, travelling directly between fields but randomly overall, suggests olfaction may not be the primary tool. The direct movement of elephants towards fields that have not been planted may suggest that elephants show episodic memory and are basing their movements on past experiences. This has been observed in chacma baboons *Papio ursinus* (Noser & Byrne 2007), where an animal is able to remember "what" to find and "where" but also " when" the timing of an event occurs. If identified as a factor, a field's history may act as a source of information to predict which fields might be targeted selectively in a season.

3.6 Conclusions

For a species that undertakes a high-risk, high-gain foraging strategy, increasing perceived risk, and reducing gain to thresholds that are no longer beneficial, may reduce human-elephant interactions. The targeting of male elephants that undertake crop-foraging through aversive conditioning techniques may be effective. As Chiyo, Moss & Alberts (2012) suggest, the spread of crop-foraging behaviour through social learning may be reduced by targeting older male elephants, while targeting younger bulls may reduce their propensity to crop-forage in the future. Elephants could be targeted with aversive conditioning techniques such as chilli pepper (Osborn 2002). Since older bull elephants had a higher probability of foraging on crops, the culling of these bulls may reduce crop-foraging. While this might be warranted for repeat crop-foragers, the practicalities of this management practice are difficult. Crop-foraging events primarily occurred at night and therefore identifying responsible elephants would be particularly difficult. Likewise, removing an elephant from a population based on its age may not prove successful. Although older elephants are more likely to forage on crops, it is not known whether crop-foraging events were carried out by the same individuals. Therefore, the lethal targeting of elephants categorised as prone to crop-foraging may not reduce crop-foraging, especially in a region with lots of older bulls. Furthermore, the removal of older bulls has negative consequences due to the loss of ecological knowledge (Slotow *et al.* 2000; Slotow, Balfour & Howison 2001; Slotow & van Dyk 2001).

The most effective strategies for minimising crop-foraging events are ones that reduce access to fields and crops. If elephants are targeting fields by traveling along direct routes that optimise movement, the use of deterrents or early warning systems along these routes may deter elephants before reaching fields. Mapping elephant movements towards fields may identify locations where deployment of deterrents would be most effective. However, as these devices would be outside farmers' fields, determining who manages and maintains them would be an important factor in their success. These techniques have their limitations, with elephants potentially circumnavigating them. Therefore, increasing perceived risk at fields, through guarding, solar lights or barriers (chilli burning or fences) may be the most feasible option for deterring crop-foraging elephants.

Chapter 4. Farmers' attitudes and influence on human-elephant interactions

4.1 Summary

- Understanding the attitudes of farmers towards elephants, and their farming practices, in areas with high numbers of human-elephant interactions is crucial for designing management practices and interventions.

- Farmers' value for, and tolerance of, elephants were determined in the Makgadikgadi region, and factors were identified that influenced these attitudes. Farming practices in the region were examined to determine whether they influenced the frequency and extent of crop-foraging events. The farmers' perception of crop-foraging events was compared to actual events to see if they differed.

- Farmers' value for elephants was influenced by the community they were from, whether elephants had entered their field that year, and if they had encountered elephants that year. A farmer's tolerance of elephants was influenced by whether elephants had entered their field that year, and the number of times they had entered.

- Farmers' reported farming practices did not influence whether or not elephants entered their field, the frequency of crop-foraging events or the extent of damage. Farmers reported preferences for growing certain crops and believed that elephants foraged on some crops more than others, even though elephants appeared to forage generally and showed no preference for specific crops.

4.2 Introduction

Understanding a community's attitude towards wildlife is crucial when analysing human-wildlife interactions (Manfredo 1989; Manfredo, Teel & Henry 2009). The impact wildlife has on people can cause negative attitudes and even retaliatory killing of wildlife (Hussain 2003; Okello *et al.* 2014). Mitigation strategies are reliant on whether communities hold positive attitudes towards wildlife as most strategies are largely influenced by the human component (O'Connell-Rodwell *et al.* 2000; Osborn & Parker 2003). For management practices to be successful they must be run and maintained sustainably by the local communities (Zimmermann *et al.* 2009; Hoare 2015). As the most successful solutions to human-wildlife interactions often involve on-farm management strategies, understanding current farming practices and how they might influence human-wildlife interactions is imperative.

Human-elephant interaction studies are often limited to investigating crop damage by elephants, elephant behaviour or demographics in relation to crop-foraging events (Naughton-Treves 1998; Hoare 1999a; Chiyo, Moss & Alberts 2012; Gunn *et al.* 2014). While this is important for developing management practices to reduce crop-foraging events, understanding farmers' attitudes towards elephants is just as important, particularly when initiating a new project.

Attitudes have been well studied in relation to human-carnivore interactions around the world, linking attitudes and perceptions to many demographic and socio-economic factors, and experiences (Lindsey, du Toit & Mills 2005; Zimmermann, Walpole & Leader-Williams 2005; Romanach, Lindsey & Woodroffe 2007; Morzillo *et al.* 2010; Heberlein 2012; Carter *et al.* 2014; Eriksson, Sandström & Ericsson 2015). Many studies interview whole populations, where different members of a community will have different concerns about the costs and benefits of wildlife. Studies have assessed the attitudes towards elephants in areas where they are absent (Hill 1998), where they affect people depending on the land use (Gadd 2005) and to understand various stakeholders' opinions and perceptions of elephants and their management (Adams *et al.* 2017). Other studies have investigated attitudes towards protected areas in relation to crop damage (de Boer & Baquete 1998). While this provides insights into how different social groups might be influenced by the presence of elephants, the attitudes of members within a social group are rarely investigated.

Rather than assessing the attitudes towards elephants of a whole community, I assessed the attitudes of the subset of the community most affected by elephants: farmers who had ploughed their field that year and were therefore likely to have attitudes influenced by crop-foraging events. More specifically, I determined farmers' value for, and tolerance towards, elephants and investigated which demographic and socio-economic factors and experiences influence these attitudes.

In the Makgadikgadi region, the climate results in short agricultural seasons, reliant on wet season rainfall (Venema & Kgaswanyane 1996). Farmers in the region plough their fields at the onset of the first rains, which vary in timing and quantity, to take advantage of the peak soil and weather conditions (Batisani & Yarnal 2010; Gupta 2013). Donkeys are the main source of ploughing power: locating and capturing them takes time and can cause delays in ploughing (Venema & Kgaswanyane 1996; personal observation). Some farmers rely on the government to plough their field which also causes delays as tractors break down or are not available (Gupta 2013). This results in high variation in the ploughing start dates for many farmers. I assessed whether the timing of key dates during the agricultural season influenced crop-foraging events. Rainfall is arguably the biggest predictor of a successful harvest in Botswana, with 15.1% of households in the study region stating that, after unemployment, the absence and unreliability of rainfall was a major constraint on livelihoods (Department of Environmental Affairs and Centre for Applied Research 2010). Therefore, it is crucial to plough fields and sow seeds at the beginning of the rainy season to take advantage of optimal soil moisture and weather conditions (Venema & Kgaswanyane 1996). Elephants target mature crops and most damage occurs prior to or during harvesting (Hillman-Smith *et al.* 1995; Bhima 1998; Hoare 1999a; Sam *et al.* 2005; Jackson *et al.* 2008). I sought to test the hypothesis that the earlier farmers plough their field and sow seeds following the first rain, the shorter the period crops will be present in fields due to rapid growth and maturation, making them less vulnerable to damage by elephants.

Since elephants forage on certain crops more than others (Sukumar 1990), fields containing particular crops incur larger areas of damage (Guerbois, Chapanda & Fritz 2012), although this is often not fully quantified. Large amounts of damage occur through trampling, not necessarily browsing, and because a field has a large percentage of a particular crop does not necessarily mean damage has been caused to that crop (Barnes *et al.* 2005; Sitati, Walpole & Leader-Williams 2005; Webber *et al.* 2011; Pittiglio *et al.* 2014). Understanding whether elephants forage on some crops more than others is useful when farmers decide what to plant. Some studies recommend converting to cash crops that are less palatable for elephants (Parker & Osborn 2006; Gross, McRobb & Gross 2016). While this might be suitable for commercial farmers, it is not practical for farmers ploughing their fields on a subsistence basis. I therefore investigated what farmers grow, what they perceive elephants to target, and what elephants forage on, to see if farmers' perceptions matched actual events.

In this chapter, I use data collected from 143 questionnaires, 141 fields and 375 crop-foraging events, collected over three years. My overall aim is to determine the attitudes of farmers in the Makgadikgadi region and identify what might influence them, and to understand how farmers managed key farming practices and the effects they had on crop-foraging events, while determining whether farmers were aware of elephant crop-foraging characteristics so that recommendations can be made to reduce their susceptibility to crop damage. Specifically, I aimed to determine:

- the farmers' value for, and tolerance of, elephants and identify farmers' traits and experiences that may influence these attitudes
- if the dates farmers complete certain farming practices influences the occurrence or frequency of crop-foraging events and/or the extent of damage
- if farmers' perceptions of crop-foraging events are aligned with actual events

4.3 Methods

4.3.1 Questionnaire

I completed questionnaires with farmers between the months of July-September 2014, with a sample of 143 farmers from Khumaga and Moreomaoto. Questionnaires were initially completed with 70 farmers that had enrolled on the project during the 2014 agricultural season but then expanded to include any farmer that had ploughed their field in 2014. Questionnaires were completed with the individual who was responsible for the field or who had registered the land with the government agricultural officers. All farmers were aged 18 and over. Government agricultural registers were used as a source to locate farmers who had ploughed their field in 2014. Over 60% of farmers in Moreomaoto (n=44) and 80% of farmers in Khumaga (n=99) that had ploughed their field and that were available completed the questionnaire.

The questionnaire was completed in Setswana or Kalanga by a research assistant (Mr Mankind Molosiwa) in my presence. Questionnaires were completed at the end of the agricultural season, at least one month after the last reported crop-foraging event to ensure that answers were measured and not based on reactions to recent events. Usually only the respondent was present during the interview, but if other members of the family or community were present, only the respondent's answers were recorded.

The goal of the questionnaire was to understand which factors affected a farmer's value for, and tolerance of, African elephants, while identifying characteristics of farming practices. The questionnaire was broken into four sections providing insight into the characteristics of the farmer, the characteristics of their field and farming practices, crop-foraging events and experiences with elephants, and their attitudes (see supplementary information 3).

Information recorded about the farmer included their sex, age, ethnicity, village they were from, length of residency, education, employment status, number of dependants and wealth (see supplementary information 3). I also recorded the number of fields owned by the farmer; when each field was ploughed; when they were planted; and when the harvest was completed in each field. The number of days that had passed since 1st August 2014, when the first farmers ploughed their field(s), was calculated to score when farmers ploughed, sowed and finished harvesting their field in relation to each other. The month the farmer completed each activity was extracted and stored. Farmers selected which crops they grew and why they grew these crops. Farmers ranked a list of crops from one to nine in order of importance for both themselves and what they perceived elephants to show preference towards when entering fields.

Farmers were asked about any crop-foraging events, their frequency, the extent and value of the damage, and the impact on the farmer's family. I also recorded whether farmers had experienced crop-foraging events in the last five years and whether they had encountered elephants in the last one or five years. Farmers were asked whether they or a family member had been directly injured by an elephant in the last 15 years. Finally, farmers were asked how much they knew about elephants.

Attitudes of value and tolerance were explored using a series of ten value statements and eight tolerance statements modelled on Gurung (2008). Interviewees could decide whether they strongly disagreed, disagreed, were neutral, agreed or strongly agreed with the statement, and their responses scored on a five-point Likert scale with 1 being low, and 5 high, agreement. The data were summarised by calculating the mean value and tolerance scores for each farmer. Tolerance statements were paired with reverse statements. Therefore, when calculating mean tolerance scores, the results from the second statement of each pair was reversed to ensure that a lower score indicated lower tolerance.

4.3.2 Crop-foraging events

I used the number of paces from transects to assess damage levels in crops (section 2.3.1). I calculated the number of paces of browsing damage for each crop as a proportion of their availability for each crop-foraging event, offsetting the number of crops available by any previous damage recorded in the field. For each crop, in each field, the amount of damage from browsing in each crop-foraging event was recorded as a proportion of the crop's availability. Crop-foraging events where cattle had also gained access were excluded from the analysis as it would not always be possible to distinguish cattle damage from elephant damage. Subsequent crop-foraging events were also excluded due to the difficulty of ascertaining what caused the damage.

4.3.3 Data analysis

All analysis was performed in R (version 3.3.2). To test the internal consistency of value and tolerance statements I performed a reliability analysis using the package "psych" (Revelle 2018). The relationship between attitude scores (value and tolerance) and categorical variables with two categories such as sex, village, employment status, whether elephants had entered the farmer's field, and whether the farmer had encountered elephants, were analysed using a Mann-Whitney U test due to significant deviation in normality of attitude scores. Categorical variables with three or more categories such as age, ethnicity, residency, education, impact and knowledge were analysed using a Kruskal-Wallis test due to significant deviation in normality of attitude scores. For the continuous variables i.e. number of times elephants entered a field, perceived percentage of damage, perceived value of damage, number of dependants and how many family members were employed outside of farming, a Spearman's rank correlation was used to determine if there was a correlation with attitude scores. Some variables (age, residency and education) were adjusted to reduce the number of categories to two and their relationship with attitude scores was determined using a Mann-Whitney U test. For full details of the statistical tests see Table S4.1.

A binomial general linear model (GLM) was constructed to determine if the date of ploughing and sowing affected whether elephants entered the field that year. To analyse the effect of timing of farming practices on crop-foraging events, Kruskal-Wallis tests were performed to determine whether the month of ploughing, sowing or completion of farming activities influenced the number of crop-foraging events, the farmer's perceived percentage or perceived value of damage. Spearman's Rank Correlations were used to determine if there was a correlation between the number of days after 1st August 2014 before ploughing, sowing, completion of farming activities, and the number of crop-foraging events, the farmers' perceived percentage or perceived value of damage.

I used a Kruskal-Wallis test to determine whether farmers placed different levels of importance on different crops and whether they thought elephants preferred to forage on particular crops. To investigate whether elephants showed foraging preference, I used a negative binomial generalised linear mixed model (GLMM) with "Event Number" nested within "Field ID" nested within "Year" as random effects to determine if the proportion of damage due to foraging (as opposed to trampling) was influenced by the crop, using the package "lme4" (Bates *et al.* 2015) and "MASS" (Venables & Ripley 2002).

4.4 Results

The questionnaire was completed by 143 farmers: 72.0% were female; 62.3% were older than Botswana's retirement age of 45; 13.3% had started secondary education; and 93.7% were unemployed, relying solely on subsistence farming for their livelihood, with a high number of people dependent on their field (Table S4.2). Only one farmer was registered as a commercial farmer.

Farmers grew a diversity of crops (Table S4.3), with 98.6% growing maize, 94.4% cowpeas and 91.6% watermelons (Figure S4.1). Most farmers (67.1%) based their crop selection on historical patterns of behaviour, with fast growing being the second most popular reason (37.1%) (Figure S4.2). Other reasons for crop selection were drought resistance, suitable for the soil type and because they were not targeted by red-billed quelea.

Most farmers ploughed and sowed in October (ploughed 18.6%, sowed 18.7%), November (ploughed 26.4%, sowed 25.2%) or December (ploughed 31.4%, sowed 32.4%); a few started in August or as late as February. Most finished in March (20.4%), April (29.9%) or May (28.5%) (Figure 4.1).

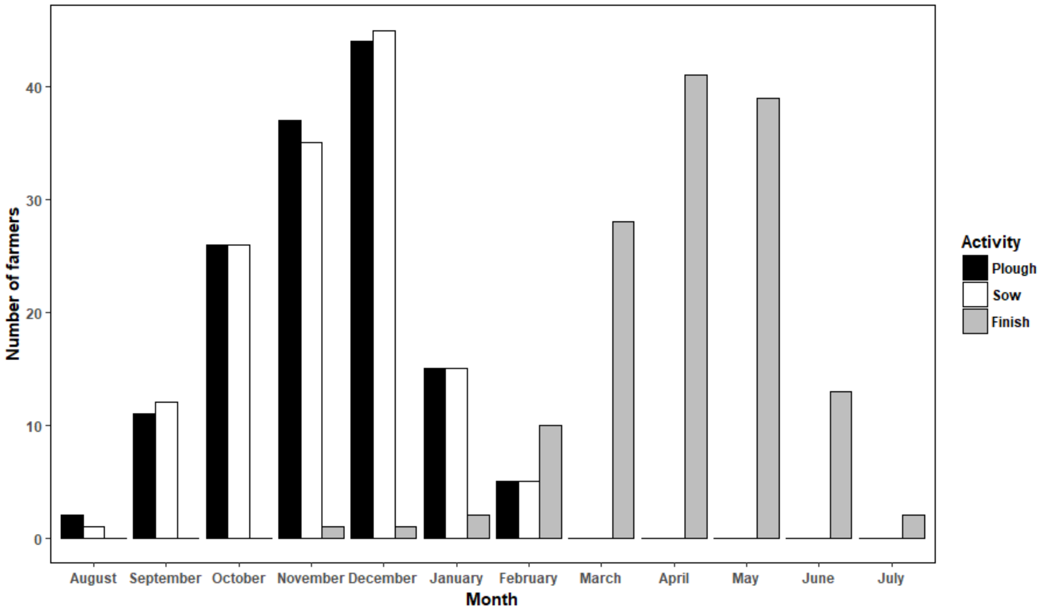

Figure 4.1. The number of farmers that ploughed, sowed and finished work in their field each month from August 2013 to July 2014

During the 2014 agricultural season, 83.2% of farmers reported elephants entering their field. Elephants entered on average 3.4 times during the season (range 1-15, SD 2.5), resulting in perceived damage estimates of 82.9% (range 0-100, SD 27.7), valued at BWP 11,587 (range 0-200,000, SD 24,811) per field. One field was removed from this calculation and subsequent statistical tests as it doubled the average damage value and was not thought to be accurate: it did not affect the analyses. These events had a large perceived impact on farmers, with 85.5% reporting the highest impact scores. Most farmers had encountered elephants in the last five years, although none reported injuries or deaths of family members (Table S4.4).

4.4.1 Attitudes towards elephants

The internal consistency of the value and tolerance scores were high (value: Cronbach's alpha=0.89, tolerance: Cronbach's alpha=0.66), suggesting that they were additive and reflective of overall value and tolerance attitudes. The farmers' mean value for elephants score was 3.4 (range 1.8-5.0, SD 0.7) and the farmers' mean tolerance towards elephants was 2.5 (range 1.0-3.8, SD 0.5). Summaries of responses to value and tolerance statements are found in Table S4.5 and Table S4.6.

Community affected a farmer's value for elephants: farmers from Moreomaoto had significantly higher values for elephants than farmers from Khumaga (Mann-Whitney U: $W_{44,99}$=1390.5, P<0.001). No other characteristics influenced a farmer's value for elephants (Table S4.7).

Farmers that had elephants enter their field that year had significantly lower values for elephants (Mann-Whitney U: $W_{119, 24}$ =1845.0, P=0.024) (Figure 4.2), and farmers that had encountered elephants in the last year had significantly lower values for elephants (Mann-Whitney U: $W_{132,11}$=1031.5, P=0.021). No other factors influenced a farmer's value for elephants (Table S4.8).

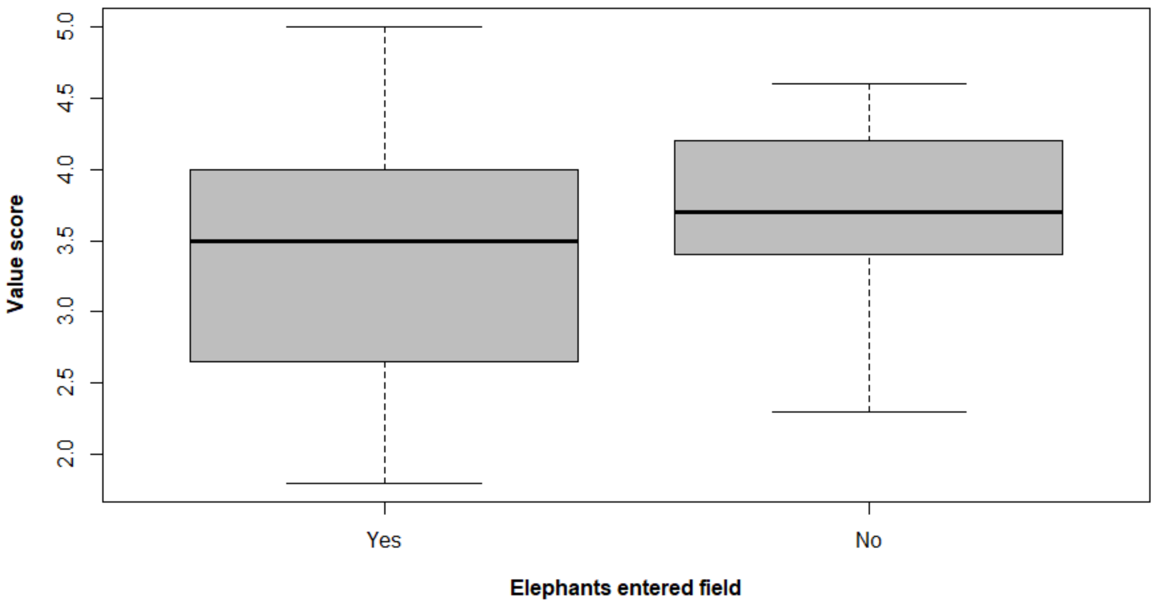

Figure 4.2. Value scores for farmers that did and did not experience a crop-foraging event in 2014 (5=higher value, 1=lower value). Box plots show the median and 25th and 75th percentiles, whiskers indicate values within 1.5 times the interquartile range

No characteristics of farmers influenced their tolerance towards elephants (Table S4.7). Farmers that had elephants enter their field that year had significantly lower tolerance towards elephants (Mann-Whitney U: $W_{119,\ 24}$=1957.5, P=0.004) (Figure 4.3). More crop-foraging events lowered a farmer's tolerance towards elephants (Spearman's rank-order correlation: r_s=-0.204, d.f.=94, P=0.047) (Figure 4.4). No other factors influenced tolerance towards elephants (Table S4.8).

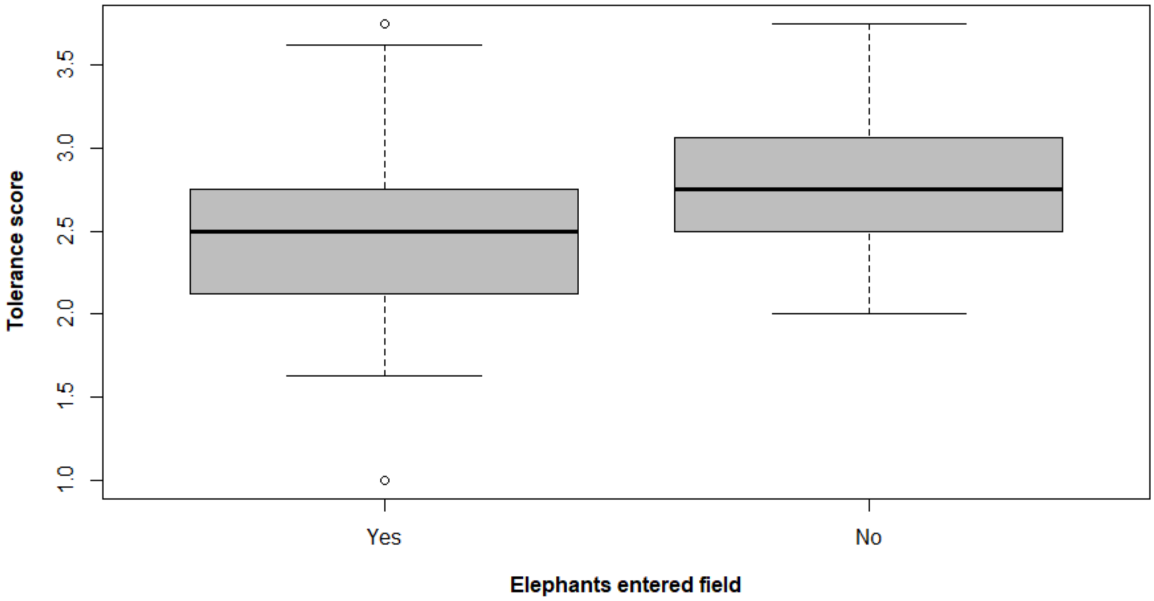

Figure 4.3. Tolerance scores for farmers that did and did not experience a crop-foraging event in 2014 (5=higher tolerance, 1=lower tolerance). Box plots show the median and 25th and 75th percentiles, whiskers indicate values within 1.5 times the interquartile range from these percentiles and circles indicate values greater than 1.5 times the interquartile range

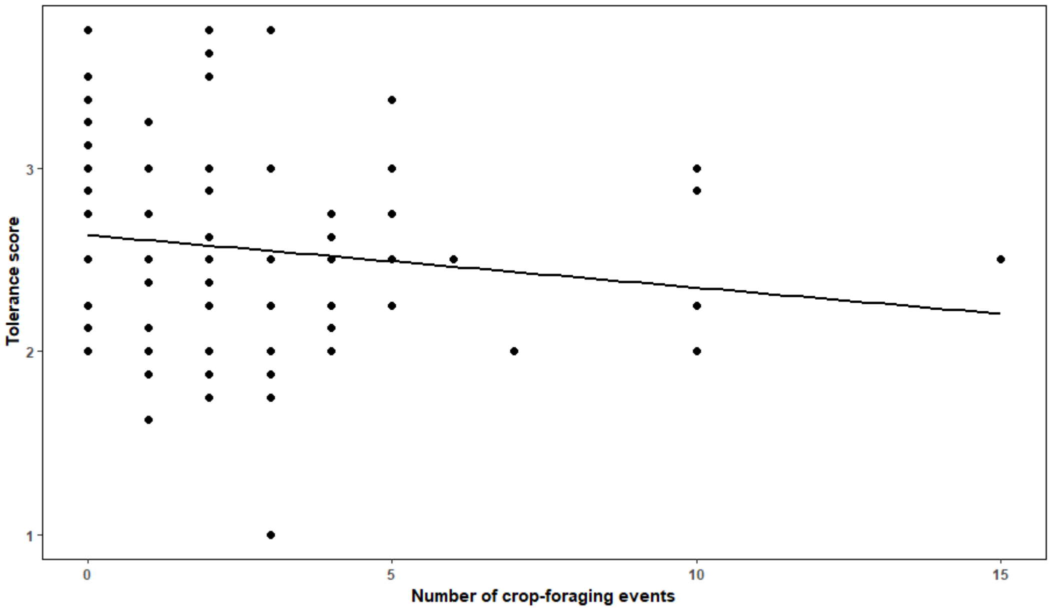

Figure 4.4. The effect of number of crop-foraging events on farmers' tolerance towards African elephants in 2014 (5=higher tolerance, 1=lower tolerance)

4.4.2 Farming practices

There was a significant correlation between how many days had passed since the farmer had ploughed and sowed (Pearson's product moment correlation: r=0.990, d.f.=138, P<0.001). For this reason, ploughing dates were not included in the model as sowing dates were the last event before elephants could start entering the field, causing damage. Sowing date had no significant effect on whether a field was entered or not by elephants (model with sowing dates compared to null model: X^2=2.283, d.f.=138, P=0.131).

Timing of farming practices (ploughing, sowing, finishing) had no significant effect on the frequency of crop-foraging, a farmer's perceived percentage or value of damage (Table S4.9). Nor did the period between sowing and finishing influence these perceived impacts of crop-foraging. Farmers with perceived damage valued over P100,000 were removed from the analysis but this did not affect the subsequent results.

4.4.3 Crop preferences for farmers and elephants

There was a significant difference in the importance of different crops to farmers (Kruskal-Wallis: χ^2=511.318, d.f.=8, P<0.001). *Post hoc* pairwise comparisons using Tukey and Kramer (Nemenyi) tests with Tukey-Dist approximations identified that maize, millet and cowpeas were significantly more important to farmers, with no significant difference in importance between the three. Sorghum, sweet reed, watermelons and pumpkins were significantly more important to farmers than butternuts and lablab, but there was no significant difference in importance between the four. Butternuts and lablab were the least important crops, with butternuts being significantly more important to farmers than lablab (Figure 4.5).

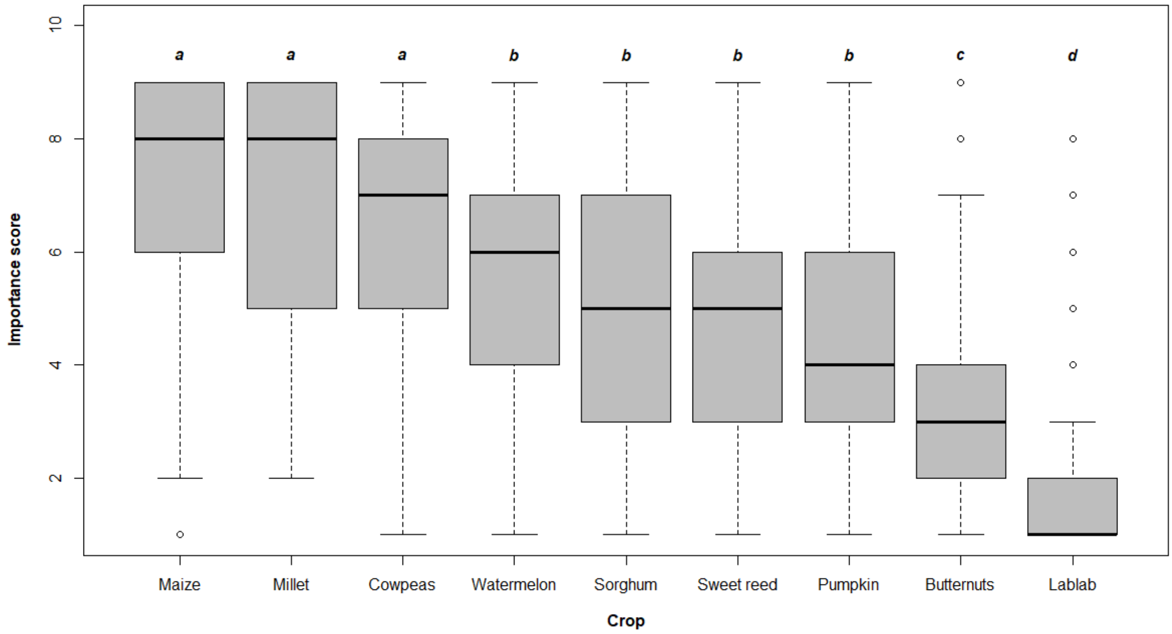

Figure 4.5. Importance of crops to farmers in the Makgadikgadi region (9=higher importance, 0=lower importance). Box plots show the median and 25th and 75th percentiles, whiskers indicate values within 1.5 times the interquartile range from these percentiles and circles indicate values greater than 1.5 times the interquartile range. Different italicised letters indicate significant differences identified by *post hoc* comparisons (Table S4.10)

There was a significant difference in the preference farmers thought elephants showed towards different crop species (Kruskal-Wallis: χ^2=572.371, d.f.=8, *P*<0.001). *Post hoc* pairwise comparisons using Tukey and Kramer (Nemenyi) tests with Tukey-Dist approximations showed that farmers believed elephants preferred watermelons when entering fields. Sweet reed and cowpeas were the next preferred crops, followed by sorghum and millet, then pumpkin, maize and butternut. Farmers believed that elephants showed the least preference for lablab (Figure 4.6).

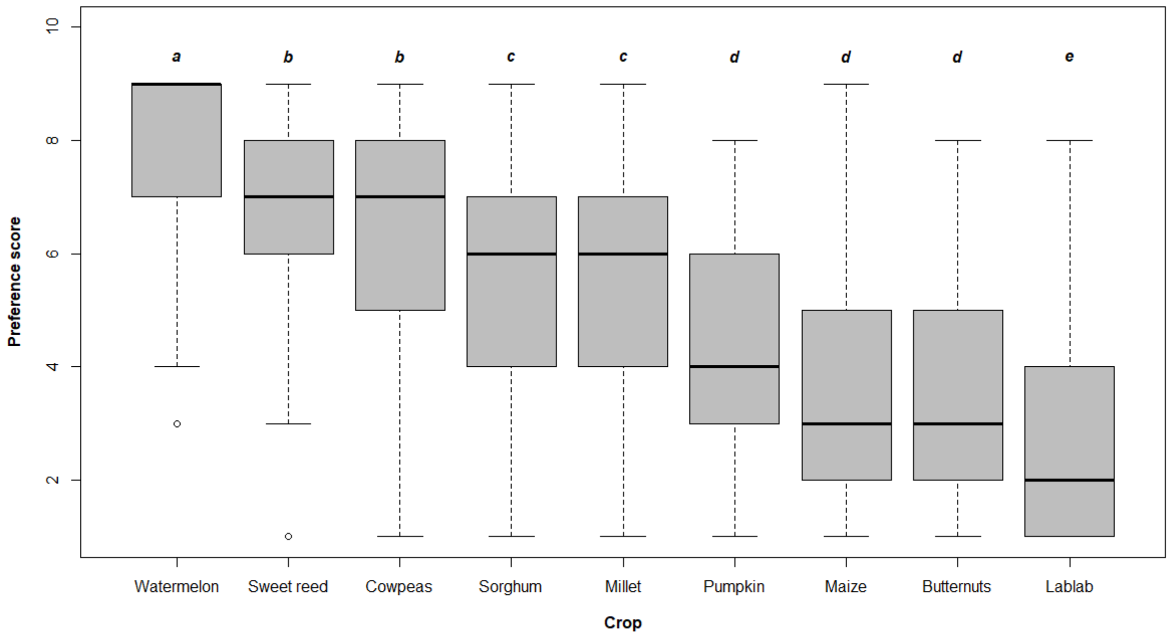

Figure 4.6. How farmers perceived African elephants' preference for crops grown in the Makgadikgadi region (9=higher preference, 0=lower preference). Box plots show the median and 25th and 75th percentiles, whiskers indicate values within 1.5 times the interquartile range. Different italicised letters indicate significant differences identified by *post hoc* comparisons (Table S4.11)

Although crop had a significant effect on the proportion of browsed damage (model with crops compared to null model: X^2=13.38, d.f.=6, P=0.037), pairwise comparisons identified no significant difference in the proportion of different crops browsed.

4.5 Discussion

Attitudes towards elephants were not influenced by inherent characteristics of farmers. While crop-foraging events and experiences with elephants influenced value for and tolerance towards elephants, this was related to the occurrence of these events rather than the amount of damage. The timing of farming practices did not influence crop-foraging events. Farmers assigned different values to different crops and believed elephants showed a preference for certain crops, even though this was not the case.

4.5.1 What influences attitudes towards elephants?

Understanding the attitudes of community members who interact with wild animals is an increasingly important aspect of conservation work. People with different demographic and socio-economic characteristics have different goals and aspirations and, coupled with varying experiences of, or encounters with, wild animals can lead to a diverse range of attitudes towards wildlife (Parry & Campbell 1992; Ericsson & Heberlein 2003; Zimmermann, Walpole & Leader-Williams 2005). Social groups are often the strongest predictor of attitudes towards wild animals (Bandara & Tisdell 2003; Ericsson & Heberlein 2003). By understanding which factors influence attitudes towards wildlife within a social group, efforts can be made to address them, with the aim of improving human-wildlife interactions.

Having examined all the characteristics of farmers, I found that only community influenced farmers' value for elephants. Local differences in attitudes have been explained by the presence or absence of wildlife benefits (Groom & Harris 2008), the distance to the nearest animal's territory (Karlsson & Sjostrom 2007) and the difference between urban and rural areas (Bandara & Tisdell 2003). However, it was hard to identify differences between the two communities I studied. In 2014, both had a tourist camp, providing benefits through local employment and income. Furthermore, the frequency and extent of crop-foraging events was unlikely to differ. Fields were spread out between both locations with no obvious spatial demarcation of “Khumaga” or “Moreomaoto” fields, possibly explaining why tolerance was not influenced. Identifying why value for elephants differs between these two communities requires further investigation.

Socio-demographic variables have varying influences on attitudes towards wildlife and wildlife areas but are not consistent across studies and are not good predictors of attitudes (Kansky & Knight 2014). The sex (Hill 1998; Nath *et al.* 2015) and education level (Gadd 2003) of respondents influence attitudes towards elephants; older respondents have less positive attitudes towards predators in Brazil and South Africa (Lindsey, du Toit & Mills 2005; Zimmermann, Walpole & Leader-Williams 2005); and wealthier respondents had increased aesthetic and scientific attitudes towards conservation (Mordi 1987). However, some of these effects may be a reflection of the respondent’s livelihood. Hill (1998), for example, found that men were more positive about elephants than women, with concerns voiced by women relating to how elephants may affect their daily activities. This probably reflects gender roles rather than women having an inherently worse attitude towards elephants. In this study, 72.0% of the farmers were women, from a similar social group, with similar education, and so were likely to have similar attitudes. Social group was the strongest predictor of tolerance towards wolves *Canis lupus* when assessing attitudes of a general population (Naughton-Treves, Grossberg & Treves 2003). As studies investigate attitudes within more specific social groups, characteristics of respondents may not be diverse enough to predict attitudes.

While farmers in the Makgadikgadi region may have similar socio-demographic characteristics, their experiences with elephants may differ. An elephant entering a farmer’s field had a negative impact on both value for, and tolerance towards, elephants. Crop-foraging events had emotional and financial impacts on the farmer that are likely to affect attitudes. The attitude of rural people towards the Maputo Elephant Reserve was only influenced by crop damage (de Boer & Baquete 1998), and negative attitudes towards wildlife could be attributed to wildlife damage to crops in northern Botswana (Parry & Campbell 1992). Farmers in the USA who reported a livestock loss to a wolf or other predator were less tolerant of wolves than those who had not reported a loss (Naughton-Treves, Grossberg & Treves 2003).

It might be assumed that it is the tangible costs of crop-foraging, such as extent or value of damage, that influence attitudes. However, it is often the intangible costs that are the main factors influencing tolerance (Kansky, Kidd & Knight 2016). Transaction costs associated with reporting events and claiming compensation each time an elephant enters a field are likely to influence tolerance (Ogra & Badola 2008), while opportunity costs such as guarding fields and repairing damaged fences are borne by farmers (Ogra 2008; Ango, Börjeson & Senbeta 2017). The compensation process in Botswana is often criticised (DeMotts & Hoon 2012), and, with high numbers of reported crop-foraging events, it might be these costs, with impacts often temporally delayed and difficult to record, that influence tolerance (Barua, Bhagwat & Jadhav 2013). This might explain why tolerance was influenced by the occurrence and frequency of crop-foraging events but not the extent of damage.

Even in the absence of impacts upon livelihoods, the presence of wildlife may cause a perceived threat (Dickman 2010), especially for a community not used to living alongside elephants. Reduced safety and restricted mobility due to elephant presence affect livelihoods and everyday lives in the region (Mayberry, Hovorka & Evans 2017). In Sweden, the direct experience with wolves influenced attitudes (Karlsson & Sjostrom 2007). However, the number of people that had direct experiences was not large enough to explain why distance to nearest wolf territory was positively associated with attitudes towards wolves, suggesting other factors influenced attitudes in the absence of direct experiences.

Identifying the hidden costs or impacts of living alongside elephants will prove crucial in addressing attitudes towards elephants. While quantitative methods allow hypotheses to be tested, qualitative methods are appropriate for gaining a deeper understanding of complex issues (Rust *et al.* 2017). A qualitative approach in the Makgadikgadi region may identify unconsidered costs that influence attitudes, providing managers and practitioners with greater knowledge of factors that need to be addressed (Ogra 2008). Moreover, this approach may identify underlying or deep-rooted social conflicts (Madden & McQuinn 2014; Evans & Adams 2016). Without addressing all the costs of living alongside elephants, both tangible and intangible, attitudes are unlikely to improve, or may even worsen.

4.5.2 Would adjusting farming practices influence crop-foraging?

Identifying farming practices that minimise the occurrence and impact of wildlife interactions would be beneficial to farmers, especially if actions can be undertaken by farmers themselves. A defined wet and dry season in Botswana means that subsistence farmers are often only able to plough their fields once per year. Ploughing fields at the earliest opportunity, the onset of rains, can increase yields significantly (Venema & Kgaswanyane 1996), but did not influence the occurrence or extent of crop-foraging. Although rare, when crop-foraging events occur, large areas of damage can result (Naughton-Treves 1998). Therefore, while reducing the “window of opportunity” for events might appear useful, it only takes a few events for significant damage to occur. A limitation of this study is that it uses farmers’ perceptions of percentage and value of damage which may not be accurate (Tchamba 1996; Gillingham & Lee 2003), due to inaccurate records, poor recall or overestimation to receive more compensation (Tchamba 1996). This is one of the limitations of using perception rather than scientifically collected damage data.

With large parts of Botswana being semi-desert, with poor soil conditions and erratic rainfall, yields can be low and they only contribute about 2.5% of Botswana’s GDP (Lewin 2011). These harsh conditions mean that farmers must be selective about what they grow. However, crop selection is still largely based on historical practices and inter-generational knowledge. Contrary to farmers' perceptions, elephants showed no preferences when foraging on crops. While the presence of certain crops in a field increases the likelihood of elephants entering that field, and higher levels of damage (Barnes *et al.* 2005; Chiyo *et al.* 2005; Sam *et al.* 2005), there is no evidence that elephants forage selectively on these crops. It is also impossible to infer preference when examining damage in general. It is unsurprising that there is no selection in a field where all the crops are more nutritious than wild forage, with Hoare (1999a) suggesting elephants select for mature growth stages rather than type of crops. One possible solution to reduce crop-foraging is to grow less palatable cash crops (Parker & Osborn 2006; Gross, McRobb & Gross 2016) but this is not practical for subsistence farmers who rely on their crops to feed their families. Trying to grow crops less palatable to elephants significantly reduces diversity of food crops, causing further problems in a region where crop selection is already restricted by the climate.

4.6 Conclusions

In most studies the strategy to improve attitudes of local communities towards wildlife and conflict are to reduce the tangible costs, often in the form of compensation schemes (Nyhus *et al.* 2005), and improve tangible benefits through ecotourism (Dickman, Macdonald & Macdonald 2011). This study found that the tangible costs of crop-foraging events such as value of damage did not influence tolerance towards elephants. My data suggest that it is the intangible costs from crop-foraging events, such as opportunity or transaction costs, that affect tolerance. Such costs are often hidden and hard to quantify but cannot be offset or accounted for through financial compensation. The main way to improve tolerance would be through reducing crop-foraging events, using mitigation strategies or better land use management. This is crucial where a large proportion of farmers experienced crop-foraging events. However, this can often be complex (Pooley *et al.* 2017), and so identifying and addressing the hidden costs or impacts of living alongside elephants may be a better way to improve attitudes.

Chapter 5. Economic costs of crop-foraging events

5.1 Summary

- Compensation for wildlife damage is a widely used tool for mitigating human-wildlife interactions. However, one of the weaknesses of this tool is that farmers often perceive the compensation to be inadequate.

- Farmers' perceived value of fields, and the resulting damage from crop-foraging events by elephants, were compared to estimated government compensation and transect estimates value of damage to determine if differences in estimates are occurring and why.

- The estimates of damage compensation differed between the farmers', government and transect method. Farmers' had the highest estimate and the transect method resulted in the lowest estimate.

- Differences between the farmers' and government estimates were attributed to the lack of compensation for watermelons, while the difference between farmers' and transect estimates could be attributed to their overestimation of damage and the proportion of bare space in fields.

5.2 Introduction

Elephants foraging on crops can impose significant economic costs to farmers at the local level (Tchamba 1996; Jackson *et al.* 2008; Mackenzie & Ahabyona 2012; Sitienei, Jiwen & Ngene 2014). These farmers often live in low income, rural areas, in communities where the impact of crop-foraging events is likely to be severe. While strategies are present to reduce interactions between people and elephants, an alternative approach is to mitigate the impact of the interaction after it has occurred. One post-interaction mitigation tool is compensation (Nyhus *et al.* 2003; Schwerdtner & Gruber 2007; Dickman, Macdonald & Macdonald 2011).

Compensation schemes reimburse individuals or their families for damage caused by wild animals to crops, livestock or property, or if individuals have been injured or killed (Nyhus *et al.* 2005). Compensation aims to increase tolerance of wildlife damage with the intention of reducing retaliatory killing, decreasing opposition to wildlife and ensuring that some of the costs of living with wildlife are transferred from stakeholders who live with wildlife to those who support conservation (Nyhus *et al.* 2005; Schwerdtner & Gruber 2007; Ravenelle & Nyhus 2017). Compensation is widely used and often managed by government or non-governmental organisations who compensate individuals after damage occurs (Schwerdtner & Gruber 2007; Dickman, Macdonald & Macdonald 2011).

Although compensation schemes are often used to mitigate human-wildlife interactions, there is disagreement on their effectiveness (Ravenelle & Nyhus 2017). Compensation can be costly and difficult to administer (Hoare 1995), causing delays in provision (DeMotts & Hoon 2012; Songhurst 2017), and can produce a moral hazard. Knowing that losses will be compensated can reduce incentives to adopt or improve management practices aimed at reducing the interactions (Nyhus *et al.* 2005; Hoare 2012). Increasing returns from agricultural production can also encourage the conversion of natural habitats to agriculture, which has adverse effects on wildlife populations (Bulte & Rondeau 2005).

Botswana employs a state-funded governmental compensation scheme for wildlife interactions for both livestock and agricultural loss (buffalo, cheetah, crocodile *Crocodylus niloticus*, elephant, hippopotamus, leopard, lion, rhinoceros *Diceros bicornis* & *Ceratotherium simum*, and wild dog), acknowledging that this is for public relations rather than to solve the problem (Hemson *et al.* 2009; Hoare 2012). Compensation claims are assessed by the Department of Wildlife and National Parks Problem Animal Control (DWNP PAC) and administered by the Ministry of Environment, Natural Resources Conservation and Tourism (MENT). In 2013 the scheme increased compensation for farmers to 100% of the cost of property damaged by elephants and lions. However, the government only compensates farmers for specific crops (cowpeas, groundnuts, jugo beans, maize, millet, pumpkin, sorghum and sweet reed) depending on whether the agriculture is commercial, horticultural or subsistence.

Farmers report that obtaining compensation takes too long and is inadequate, often overestimating the quantity of damage (Tchamba 1996; Hoare 1999a; Naughton, Rose & Treves 1999; Bandara & Tisdell 2002; DeMotts & Hoon 2012; Hoare 2012; Hoffmeier-Karimi & Schulte 2014; Ravenelle & Nyhus 2017). Although studies have compared actual compensation received to perceived losses and reported differences, few have compared these estimates to first hand assessment by a neutral third-party to determine the causes of any differences.

Although the Botswana compensation scheme only addresses the symptoms of conflict, the requirement of farmers to report crop-foraging events to receive compensation results in the production of large data sets from across the country. The main species to forage on crops and cause damage in the Makgadikgadi region is the African elephant. This makes it possible to determine the economic costs of living alongside elephants and examine how farmers perceive these costs, and compare these with government compensation for farmers and scientific estimates to see if, and why, farmers overestimate damage.

In this chapter, I use data collected from 59 fields, 214 crop-foraging events and 47 questionnaires with farmers who had elephants enter their field, to determine what influences disparity in compensation estimates between farmers and compensation schemes, and why farmers may overestimate damage. Specifically, my aims were to:

- determine damage estimates for farmers, PAC and transect estimates
- identify if there are differences between these estimates
- identify the factors that might cause these differences

5.3 Methods

5.3.1 Estimates of damage for different compensation techniques

The total value of damage due to elephants entering fields at the end of the 2015 and 2016 agricultural seasons was determined following different compensation techniques for each field attended. All estimated values of damage were calculated using the Botswana Pula (BWP) (BWP 1=0.1USD). Below I outline how I collected the data and how estimates of damage were calculated (see supplementary information 4 for example calculations).

Farmers' perceived value of damage: Questionnaires were completed with farmers at the end of each agricultural season to determine their perceived value of damage due to elephants: farmers estimated the value of the crops in their field and then estimated the percentage of damage due to elephants. However, most farmers were unable to provide a general estimate for the value of the crops in their field. Therefore, farmers were asked to estimate the quantity of each crop they expected to harvest. For example, if they had grown maize, then how many 50kg units of maize did they expect to harvest? Farmers then estimated the value of each unit, for each crop. For cowpeas, groundnuts, maize, millet and sorghum, I calculated the value per 50kg bag based on the farmer's unit size (12.5kg, 25kg or 50kg) and value of each unit. For pumpkin, sweet reed and watermelons, I calculated the value per load.

A value of the farmer's field could be determined based on these values. Calculations were performed with the farmer present to ensure that the estimated value of the field was accurate. Farmers were asked to confirm whether they agreed with the estimated value of their field. They were then asked what percentage of damage occurred in their field due to elephants entering. An estimate for the value of damage was then calculated based on the value of the field and the percentage of damage. Farmers were asked if this value estimate was accurate: none of the farmers disagreed with the estimated value of their field or of the damage.

Farmers' value of damage adjusted for average crop values: I averaged the farmers' estimated value for each crop to determine the average value for cowpeas, groundnuts, maize, millet and sorghum per 50kg bag and pumpkin, sweet reed and watermelon per load. I used these average values for each crop to calculate the farmer's estimated value of damage adjusting for average crop values.

PAC value of damage: The DWNP collected data on crop-foraging events in Botswana through their PAC unit. Farmers reported incidents of human-elephant interactions (i.e. crop damage, property damage, injury or death of livestock due to elephants, injury or death of a person, injury or death of an elephant) to the PAC office in the village of Rakops (approx. 60-80km from the study site). Members of the community were encouraged to report these incidences to either the Kgosi (village chief), police, DWNP officer in the village or the Rakops PAC office within seven days of the incident occurring. PAC officers attended these reports by visiting the location of the incident to verify the damage. PAC officers completed a DWNP PAC Investigation Diary recording general information about the incident, a statement from the farmer, information about the farmer, location of incident, type of damage, management practices in place, description of the damage and measurements, further comments and recommended compensation.

To determine the value of damage, PAC officers calculated the area of damage (ha) in the field by walking around the damaged areas with a GPS or surveyors wheel. The number of crops planted in the field were recorded. The area of damage was divided by the number of crops present in the field. Each crop in the field was designated an equal quantity of damage irrespective of the crop composition within the damaged area. The area of damage was then multiplied by the value of compensation/ha for each crop, determined by the DWNP (Table S2.2) and summed to determine a value of damage in the field. All crops received compensation except for watermelons. Although damage to watermelons was not compensated, watermelons were still included when determining the number of crops present. If compensation was approved, a list was produced with the ID number of the event, name of the farmer and the amount paid, among other pieces of information. I was provided with access to this compensation list and used it to gather information on farmers in the Makgadikgadi region whose fields I had attended. At the end of 2016 this list had not been completed for crop-foraging events occurring in 2016. I was therefore granted access to the DWNP PAC Investigation Diary for individual fields. I extracted the number of crops grown, area of damage, farmer's name and incident ID from these reports. I then calculated the PAC estimate of damage for each field.

PAC value of damage using the PAC approach: There were several reasons why farmers did not receive compensation from the DWNP. Farmers required certificates of land ownership to register their land and apply for compensation. Molapo fields on the edge of the Boteti River were rarely registered as the government does not recognise them as fields and so farmers could not apply for compensation (Venema & Kgaswanyane 1996). PAC officers were unable to attend some crop-foraging events, and there were often long delays before PAC officers attended. This meant that cattle frequently entered the field before PAC officers were able to attend, resulting in limited evidence of elephant damage and spoor. Rainfall during the wet season could disturb evidence of damage, making it difficult to determine what caused the damage. PAC officers may have chosen not to compensate farmers if they could not see signs of elephant damage. Farmers were also required to provide sufficient evidence that barriers were adequate and mitigation measures were in place to be eligible for compensation. If this was not the case, then compensation could be denied.

Some farmers chose not to report crop-foraging events to the DWNP due to the effort involved for the perceived small value of compensation. Consequently, several fields that I attended over the course of the season that were entered by elephants did not receive compensation. For these fields I estimated damage using the same approach as the PAC, based on the ploughed area of the field and the number of crops present for all fields I attended (section 2.3.1). I used the farmer's percentage damage estimate to calculate the area of damage. I then followed the PAC method of estimating damage for these data.

PAC value of damage using the PAC approach including uncompensated crops: The PAC method for calculating compensation excluded watermelons. Having calculated estimates of damage following the PAC method, I also calculated estimates of damage including watermelons.

Transect value of damage: Having completed transects to assess damage after crop-foraging events in fields, an area of damage (ha) was determined for each crop (section 2.3.1). Using the value of compensation/ha for each crop determined by the DWNP, an estimate of damage for each crop was calculated and then summed to determine the total estimate of damage in the field.

Transect value of damage if 100% damage to crop: The crop composition of the field was determined using transects and the area of damage for each crop was determined (section 2.3.1). The value of compensation/ha for each crop as determined by the DWNP was used to calculate the value of each crop in the field. This was used to estimate the damage, assuming 100% damage to the crop.

Transect value of damage if 100% damage to crop and no bare space: The area of bare space in the ploughed area of fields in the Makgadikgadi region was high. On average 40.8% of a ploughed area was bare space (chapter 2). This could be due to poor seed germination, farming management or climatic effects. So, the crop composition and size of ploughed area was used to estimate damage assuming no bare space and 100% damage (section 2.3.1). The area of each crop was calculated, and a value of damage was calculated using the value of compensation/ha for each crop before being summed to calculate the total estimate of damage.

5.3.2 Expected vs actual income

To identify which factors might cause differences between perceived estimates of damage and compensation provided, I calculated the expected income of farmers before crop-foraging events. Using the farmer's percentage of damage, I calculated the predicted income after events. I then used the PAC estimate for crop value using the PAC approach and the farmer's percentage estimate of damage to calculate the total compensation the farmer would receive. I then calculated the actual income the farmer would receive with compensation. Finally, I calculated the percentage difference between the expected income before crop-foraging events and the actual income with compensation. This was performed for each field.

I adjusted the above scenario (scenario 1) based on several factors. For scenario 2, I adjusted the farmer's expected income before crop-foraging events by using average farmer crop values rather than the farmer's crop value. For scenario 3, I adjusted for uncompensated crops by removing watermelons from the farmer's expected income before crop-foraging events. Finally, for scenario 4, I used my percentage damage which was recorded when completing transects.

5.3.3 Data analysis

To determine if there was a difference in estimates of damage between farmers, the PAC and transect method, I used a one-way ANOVA with repeated measures. Estimates of damage were $\log_{10}$ transformed to generate normally distributed data. Results were corrected using the Huynh-Feldt correction because they did not meet the assumption for sphericity. *Post hoc* pairwise comparisons using paired t-tests were performed to determine which techniques were significantly different.

To determine if the farmers' perceived crop value influenced the observed differences (section 5.4.3), I calculated average values for each crop based on all the farmers' crop values. The farmers' estimates of damage were adjusted using these average values to see if their perceptions of crop values influenced their estimate of damage. The data were not normally distributed, and transformation of the data did not improve the distribution. I used a Wilcoxon matched pairs test to see if there was a difference in estimate of damage between the farmers' estimates and the farmers' estimates when adjusted for average crop values.

To determine if uncompensated crops caused this difference, I compared the PAC estimates of damage using the PAC approach with the PAC estimate of damage using the PAC approach including damage for uncompensated crops. A $\log_{10}$ transformation of the data produced normally distributed data and a paired t-test was used to analyse differences between the mean estimate of damage for these two scenarios. Since there was a significant difference between these estimates of damage (section 5.4.4), I compared the farmers' estimate of damage with the PAC estimate using the PAC approach including uncompensated crops. Since the data could not be transformed to produce a normal distribution, I used a Wilcoxon matched pairs test to see if there was a difference in damage estimates between the farmer and the PAC estimate using the PAC approach including uncompensated crops.

I used a one-way ANOVA with repeated measures to see if there were differences in estimates of damage between different compensation techniques. I looked for differences between the farmers' estimate, PAC estimate using the PAC approach with and without uncompensated crops, transect estimate of damage, transect estimate of damage if 100% of the field was damaged and transect estimate of damage if 100% of the field was damaged and there was no bare space. Results were corrected using the Greenhouse Geisser correction because they did not meet the assumption for sphericity. *Post hoc* pairwise comparisons using paired t-tests were performed to determine which estimates were significantly different.

A Friedman test determined if the scenario influenced the percentage difference between the predicted income if the farmer did not have elephants enter and the actual income if the farmer did have elephants enter and received compensation. Potential outliers as shown by boxplots were removed before analysis. Three fields were removed but their removal had no effect on the results. *Post hoc* tests were performed to see which scenarios produced significantly different results.

5.4 Results

5.4.1 Crop-foraging events and reports

Between 2015 and 2016, I attended 59 fields to determine the amount of damage that had occurred due to elephants entering and attended 214 crop-foraging events. Questionnaires were completed with 20 farmers in 2015 and 27 farmers in 2016 who had elephants enter their field that year. Of these 47 farmers it was possible to calculate estimates of crop value and damage for 36 farmers following the different techniques. There were 13 reports available from the PAC office for compensation that had been approved (seven in 2015 and six in 2016).

In 2015 and 2016, 72 farmers reported crop-foraging events to the DWNP PAC office in Rackops based on their PAC register data. I attended crop-foraging events for 35 of these farmers (48.6%). However, I attended a further 20 in 2015 and 14 in 2016, who did not report crop-foraging events to the DWNP PAC office.

5.4.2 Estimated field values and damage

On average farmers valued their field at BWP 8283 (range 600-28,250, SD 7206) or BWP 10,697/ha (range 625-40,476, SD 9784). The average PAC estimate of field value was BWP 2428 (range 305-8234, SD 2017) or BWP 3011/ha (range 1025-8760, SD 1848). However, when including watermelons this estimate increased to BWP 6656 (range 305-27,979, SD 6235) or BWP 6453/ha (range 1450-15,360, SD 2625). I estimated the value of fields to be BWP 2522 (range 156-17,086, SD 3210) or BWP 5041 (range 212-27,531, SD 6270) if I ignored the area of bare space in the fields using the transect method.

On average a farmer estimated that 86.3% (range 25-100, SD 23) of their field was damaged by elephants, resulting in BWP 6957 (range 600-28,250, SD 6473) worth of damage. Using the farmers' estimated percentage of damage resulted in estimates of damage following the PAC method of BWP 2069 (range 76-7358, SD 1639). This increased to BWP 5620 (range 76-20,984, SD 5069) when including watermelons in the compensation estimate. I estimated that on average 45.2% (range 1.3-100, SD 34) of a field was damaged at the end of a season, resulting in BWP 943 (range 9-3658, SD 1102) worth of damage using the transect method. Assuming 100% damage, this value increased to BWP 2522 (range 156-17,086, SD 3210) and if there was 100% damage and no bare space in the field this increased to BWP 5041 (range 212-27,531, SD 6270).

5.4.3 Is there a difference between the farmers', PAC and transect estimate of damage?

Farmers had the highest estimate of damage, followed by the PAC and then the transect estimate of damage (Figure 5.1). There was a significant difference between the estimates of compensation for the three compensation techniques (one-way ANOVA with repeated measures: $F_{2,70}$=59.24, P<0.001, n^2=0.376 using a Huynh-Feldt correction for sphericity on P).

Post hoc pairwise comparisons using paired t-tests (*P*-value adjusted using Bonferroni method) showed that all techniques resulted in compensation estimates that were significantly different from each other (farmer-PAC: $P<0.001$, farmer-transect: $P<0.001$, PAC-transect: $P<0.001$).

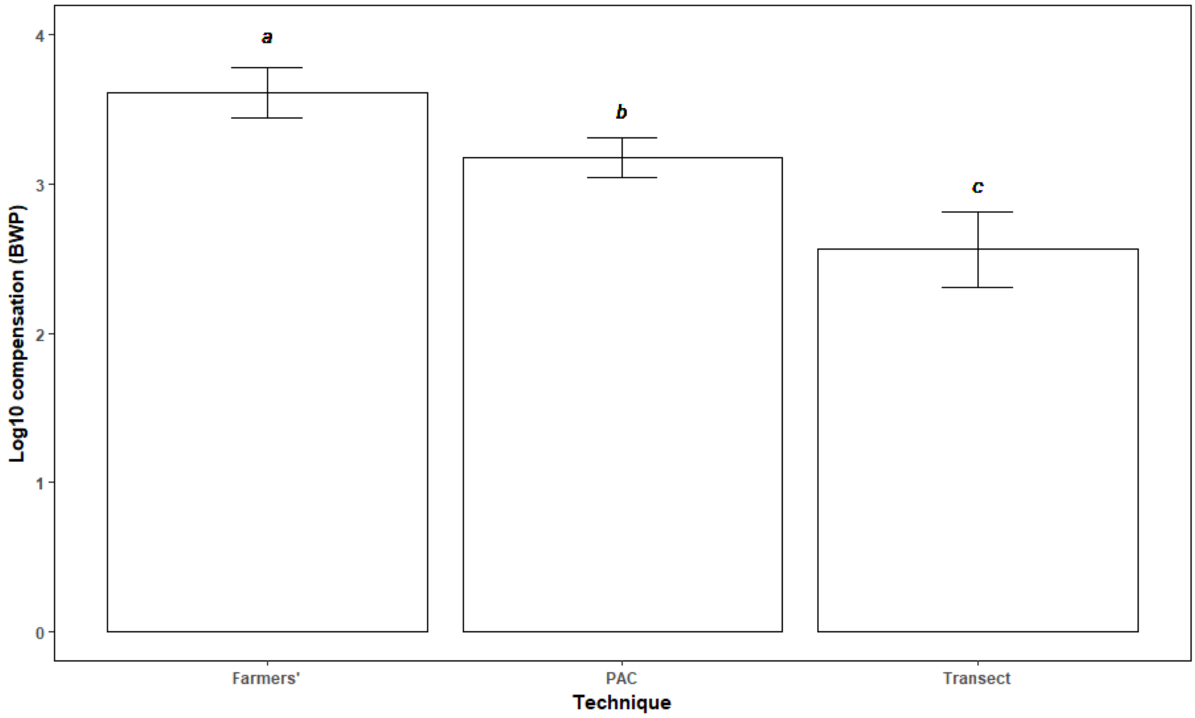

Figure 5.1. The average $\log_{10}$ transformed estimates of damage for farmers', PAC and the transect technique. Different italicised letters indicate significant differences identified by *post hoc* comparisons

5.4.4 What causes these differences?

After adjusting the farmers' estimate of damage for average crop values there was no significant difference between the medians of the farmers' estimate and the farmers' estimate adjusted for average crop values (Wilcoxon matched pairs test: V=234, N=36, P=0.123). As there was no significant difference between these two estimates, it was not necessary to compare the farmers' adjusted estimate of damage to the PAC estimate.

PAC estimates of damage including watermelons had a significantly higher value of damage than PAC estimates excluding watermelons (paired t-test: t=-11.522, d.f.=35, P<0.001). When comparing the farmers' estimate of damage to the PAC estimate of damage including watermelons, there was no significant difference between them (Wilcoxon matched pairs test: V=422, N=36, P=0.166) (Figure 5.2).

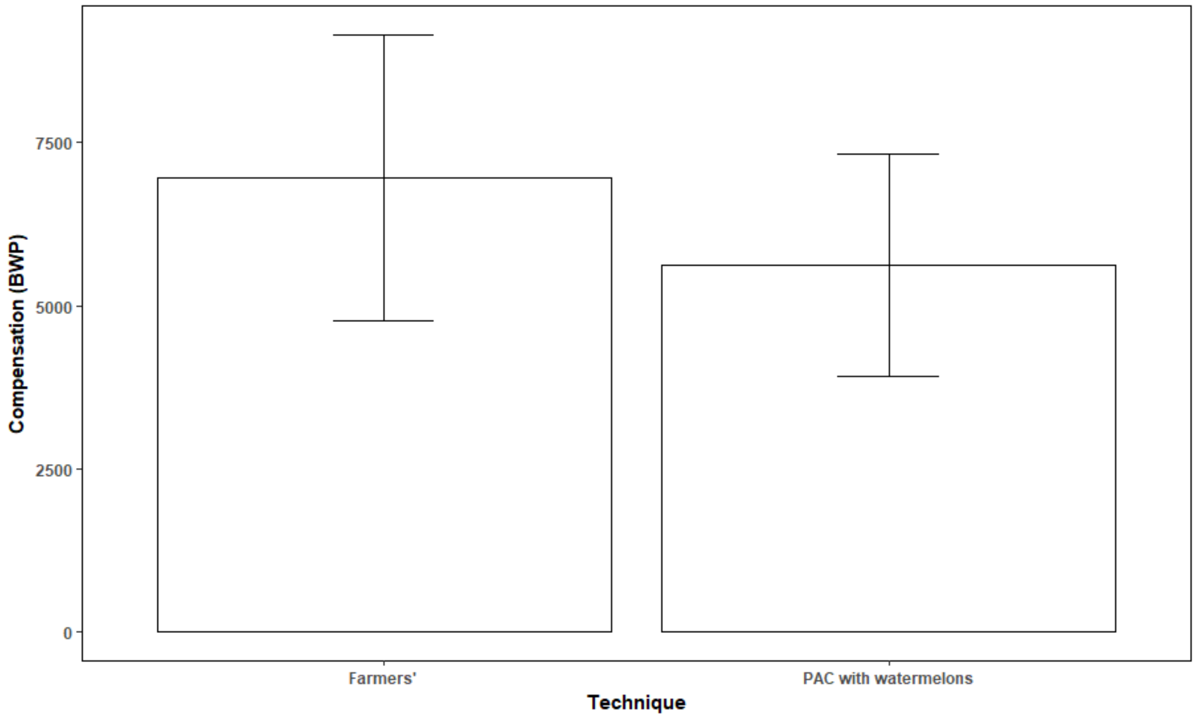

Figure 5.2. Average estimates of damage for farmers' and PAC estimates after compensating for watermelons

5.4.5 How do transect methods compare to farmers' and PAC estimates of damage?

The technique used to calculate compensation resulted in significantly different estimates of compensation (one-way ANOVA with repeated measure: $F_{5,175}$=47.193, P<0.001, n^2=0.302 using a Greenhouse-Geisser correction for sphericity on P). *Post hoc* pairwise comparisons using paired t-tests (P-value adjusted using Bonferroni method) showed that the farmers' estimates, PAC estimates including watermelons and the transect estimate when assuming 100% damage and no bare space had the highest estimates of compensation, followed by the PAC estimate and the transect estimate of compensation when assuming 100% damage. The transect method gave the lowest estimate of compensation (Figure 5.3).

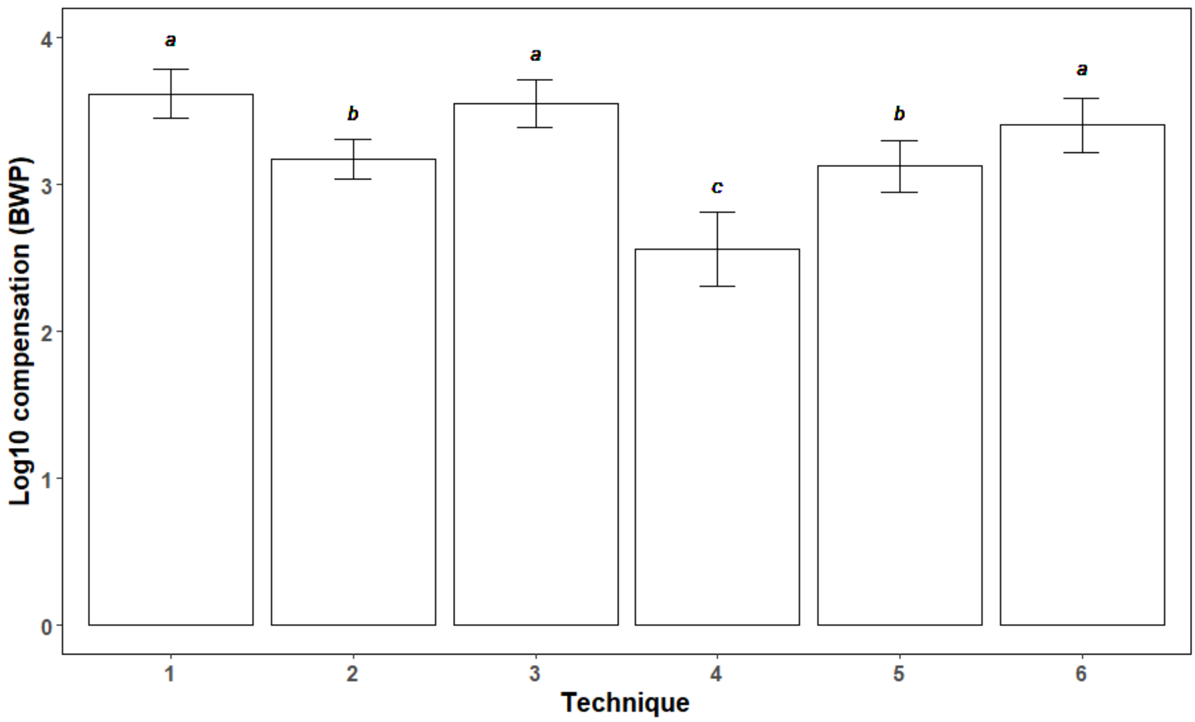

Figure 5.3. The average $\log_{10}$ transformed estimates of damage for: 1) farmers, 2) PAC, 3) PAC including watermelons, 4) transect method, 5) transect method assuming 100% damage, and 6) transect method assuming 100% damage and no bare space techniques. Different italicised letters indicate significant differences identified by *post hoc* comparisons (Table S5.1)

5.4.6 Does the compensation scenario influence the difference between predicted and actual income?

The scenario used to calculate the difference between predicted and actual income resulted in significantly different median percentage differences between predicted and actual income (Friedman test: x^2=32.222, d.f.=3, P<0.001) (Figure 5.4). There was no significant difference in the percentage difference between predicted and actual income between scenario 1 (standard) and scenario 2 (adjusted for average crop values). There was also no significant difference between scenario 3 (uncompensated crops) and scenario 4 (adjusted percentage damage). However, there were significant differences between scenario 1 (standard), and scenarios 3 (uncompensated crops) and 4 (adjusted percentage damage), with scenarios 3 and 4 having significantly lower differences between predicted income and actual income. The same result occurred between scenario 2, and scenarios 3 and 4 (Table S5.2).

Under the current system, a farmer's perceived actual income after estimated compensation was 44.3% lower than their projected income if elephants had not entered their field. When the farmer's perceived value of projected income before crop-foraging events was adjusted for average crop values, this difference increased to 56.5%. When the farmer's perceived value of projected income before crop-foraging events was adjusted by removing uncompensated crops from the estimate, the difference decreased to 33.1%. Finally, when the percentage of damage was adjusted using estimates from transects, the percentage difference decreased to 24.1%.

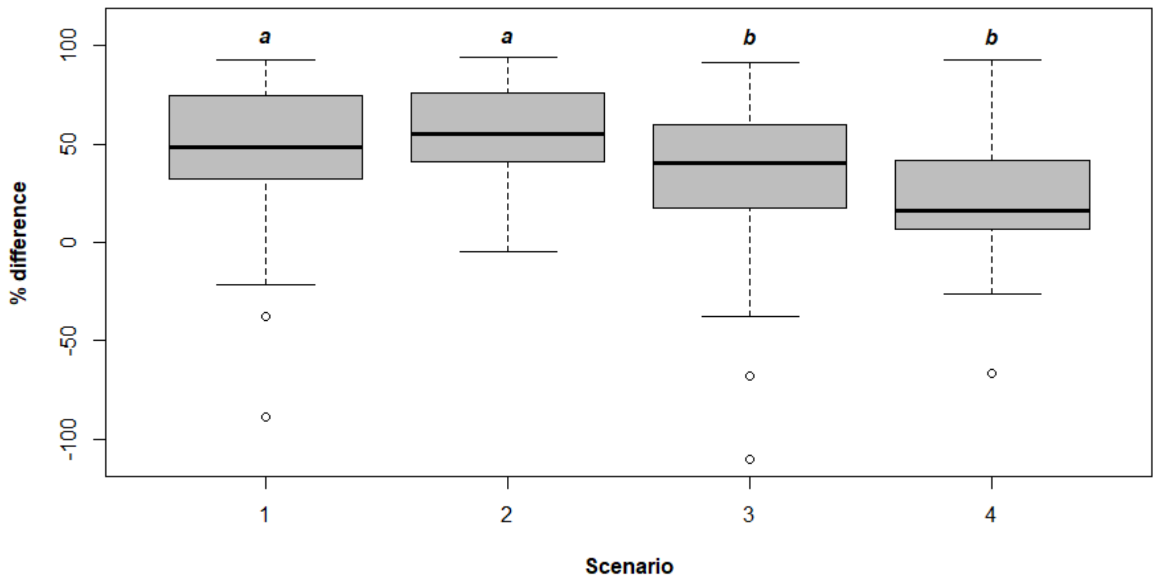

Figure 5.4. The median percentage difference between predicted and actual incomes for: 1) standard, 2) adjust predicted income for average crop values, 3) adjust for uncompensated crops, and 4) adjust for percentage damage scenarios. Different italicised letters indicate significant differences identified by *post hoc* comparisons

5.5 Discussion

Differences were observed between farmers and the PAC in estimates of damage when elephants had entered fields during an agricultural season. Farmers' estimates of damage were higher. However, when uncompensated crops (watermelons) were included in PAC damage estimates there was no difference between farmer's and PAC damage estimates.

Estimates of damage using transects were lower than both the farmers' estimates and the PAC. However, when the transect estimate of percentage damage was increased to assume 100% damage and no bare space in the field, there was no difference between transect estimates, PAC estimates or farmers' estimates.

The compensation scenario influenced the difference between actual and predicted income if elephants had not entered. Adjusting farmers' predicted income for uncompensated crops and percentage damage resulted in lower differences between predicted and actual income in comparison to the current scenario of compensation taking place.

There appeared to be two reasons for the estimates of damage varying between the compensation scenarios. Firstly, the compensation system currently in place does not compensate for watermelons in Botswana. Secondly, differences might occur due to the perceived extent of damage and crop density.

5.5.1 Compensation system

Perceived fairness of a compensation scheme is crucial in determining its success: not compensating for certain crops can make schemes unfair and ineffective (Nyhus *et al.* 2003; Watve *et al.* 2016). Assuming the perceived extent of damage was identical between both farmers and the PAC, and watermelons were included in the PAC damage estimates, there would be no difference in the value of damage between the two techniques. Farmers often stated that not compensating for damage to watermelons was unfair. The government does not compensate for watermelons in subsistence fields. Compensation is only provided if a farmer registers their field under horticulture (which requires further farmer input). The government takes a similar stance for compensating livestock losses. Compensation is provided for livestock losses caused by lion, leopard, African wild dog and cheetah but not spotted hyaena or black-backed jackal *Canis mesomelas* (McNutt *et al.* 2017). This can cause conflict between farmers and the government because farmers are still losing livestock to wildlife but because it is caused by an ineligible species, compensation is not provided (McNutt *et al.* 2017). The high value of watermelons and lack of compensation may explain the farmers' resentment about compensation in the region, which may influence their attitudes towards elephants.

One limitation of this result is that the percentage of damage was controlled for in both techniques. Limited reports from PAC officers meant that it was impossible to determine the percentage of damage PAC officers reported and therefore the farmer's percentage of damage was used to calculate PAC compensation. If farmers overestimated the percentage of damage in fields, this will also affect the PAC estimate. However, Songhurst (2017) found that PAC records showed a greater mean area of damage per incident than community enumerators following the IUCN data collection and analysis protocol for human-elephant conflict situations in Africa (1.39ha for PAC records, 0.29ha for community enumerators) suggesting that the PAC perception of extent of damage may also be inflated.

Interestingly, the compensation system was not influenced by the generalisation of crop composition when calculating rates following the PAC protocol, which does not account for the crop composition. For maize, millet and sorghum, compensation rates are relatively similar per hectare (BWP 900, 700, 870 respectively), whereas cowpeas and sweet reed have higher values (BWP 2500, 2000 respectively). Fields with pumpkins and watermelons present are likely to be most affected due to much higher crop values per hectare (BWP 16,500). Similar crop values for the main crop species grown in the area are likely to reduce the effect of designating an equal quantity of damage to each crop, irrespective of the crop composition within the damaged area. If crops had high variation in their value, estimates of damage may not be representative of actual damage under the PAC compensation protocol.

5.5.2 Perception of damage

The second reason for differences between the compensation techniques was in the assessment of damage. Farmers' estimates of extent of damage were nearly double estimates of damage following a scientific assessment protocol (transects). Tchamba (1996) found farmers overestimated crop damage by 30-40% suggesting this was with the aim that potential compensation would be related to the level of damage declared.

By nature, assessing damage is subjective. Even compensation for livestock damage can prove difficult. A farmer may not accept less compensation just because a calf has been killed as opposed to an adult cow because its future worth would have been much more (Nyhus *et al.* 2003). In Botswana, cattle are also culturally valued above their economic value, and therefore compensating for lost livestock can cause differences of opinion between farmers and the government (Mordi 1989). It is therefore understandable that there will be differences in opinion for damage to crops in large, polyculture fields.

Damage by elephants is visually measurable in comparison to many other species where observable damage might be delayed; for example, when wild boar *Sus scrofa* chew the root or stem base of plants resulting in them drying out (Bayani 2016) or when it is hard to visually observe, as in quelea damage where seeds are removed from the standing crop, leaving the plant in place (Allan 1996). Bayani (2016) found that visual inspection did not reflect realistic loss, with low correlation to net loss of grain yield most likely due to the prevalent herbivore species present doing less noticeable damage. However, in the Makgadikgadi region one of the main species damaging crops are elephants, although cattle also cause substantial damage as a consequence of elephants entering fields (section 2.4.7). Therefore, the net loss caused by elephants is likely to be proportional to the area of visible damage. All estimates of damage were determined using visual assessments, in situ, either pacing around damaged areas (PAC), recording damage during transects (scientific protocol) or visually assessing the damage (farmer). These protocols are suited to events that are low frequency with a high extent of damage, which matches elephant crop-foraging scenarios (Naughton-Treves 1998; Gillingham & Lee 2003; Hoffmeier-Karimi & Schulte 2014). Visually assessing crop damage caused by elephants would provide good estimates of damage, with variation occurring due to the method employed but also perceptions of the damage.

Other wildlife species were observed to cause damage to crops on occasion such as ground crickets and quelea but this was not compensated. Although I only recorded damage by elephants, or the resulting damage if cattle entered after elephants, damage from other species may cause differences in extent of damage. However, farmers were asked how much damage had occurred in their field due to elephants entering and would often separate loss of crops to other factors, such as lack of rain.

To ensure that initial emotion to crop-foraging events did not influence damage estimates, questionnaires were not completed with farmers directly after crop-foraging events: after crop-foraging events farmers would often state that everything had been destroyed when crops were still present in the field. The time lapse between events and questionnaire completion may have increased the probability of recall bias affecting estimates. While this is a possibility, I felt that initial emotion could have a greater effect on biasing estimates.

Farmers were asked for their estimated value of fields during questionnaires. These estimates were based on what they expected to harvest. Several farmers mentioned that they were unsure of how much their crops were worth because they were yet to have a successful harvest due to elephants or the climate. Although this may have meant some farmers' estimates were less accurate, it is still the farmers' perception of value and damage that is being investigated, and it is these perceptions that are used to determine whether compensation is acceptable.

Another limitation is that some farmers would not report when their field had been completely damaged (normally after livestock entered) as they did not believe this was useful and so the transect estimates of damage may be underestimated. Although a limitation, this was unlikely to occur regularly as there was a financial incentive to report all crop-foraging events and I always maintained good communication with farmers.

While perceptions of damage may be a reason for differences between transect estimates and farmers' estimates, the large areas of bare space between crops may also influence differences. When 100% crop damage was assumed, it did not result in comparable damage estimates between transect estimates and farmers' estimates. Farming in the Makgadikgadi region can be difficult. Crops may not germinate due to lack of rain or poor soil quality. This results in patchily distributed crops. While space between crops is important to reduce competition for water, light and nutrients, leading to higher productivity, large areas of bare space also reduces the total yield of a field. Bare space in fields accounted for 40.8% of the ploughed area. If farmers do not acknowledge these large areas of bare space, this might be why their estimates of damage are high in comparison to transect estimates. Farmers are aware of the size of the ploughed area but may not have a good perception of the density of crops within the field. The PAC protocol does not consider the density of crops and this might explain why, when watermelons are included in compensation estimates, estimates are similar between the PAC and farmers.

5.5.3 No compensation

I assumed all farmers receive compensation. However, this is not the case. In 2014 and 2015, 68 and 43 farmers respectively reported crop damage to the DWNP PAC from the study area, but only 26 and 24 had their claims approved. In 2016, 29 farmers reported crop-foraging events, but it was not possible to determine how many had been approved. There are several reasons farmers may not receive compensation (section 5.3.1). Thus, there is a large subset of farmers in the study region that do not receive compensation for wildlife damage, exacerbating conflict between stakeholders.

Government compensation schemes often result in communities seeing wildlife as belonging to the government (DeMotts & Hoon 2012). Therefore, when elephants enter farmers' fields they believe the government should compensate appropriately. When this does not happen, it can result in underlying conflicts (Madden & McQuinn 2014) which can be much more damaging in the long term than the impacts. As stakeholder relations deteriorate, resolving negative interactions becomes more difficult.

5.5.4 Does compensation increase tolerance?

Even if the financial loss to the farmer is fully compensated, this does not necessarily mean that their opinions about wildlife will improve and farmers will be appeased (Naughton-Treves, Grossberg & Treves 2003). Although their economic costs from damage will have been met, the assumption of opinions or tolerance improving through compensation has limitations (Naughton-Treves, Grossberg & Treves 2003; Marino *et al.* 2016; McNutt *et al.* 2017). There are many indirect costs that are not addressed through compensation because they are not economic or related to the impact. For example, the cost of guarding fields or effort involved implementing mitigation strategies (Mackenzie & Ahabyona 2012), costs associated with reporting conflict and receiving compensation (Bal *et al.* 2011; DeMotts & Hoon 2012) and the hidden impacts such as reduced psychosocial wellbeing, disruption of livelihoods and the stress of food insecurity (Ogra & Badola 2008; Barua, Bhagwat & Jadhav 2013). The nature of subsistence farming means that farmers do not have to purchase staple foods. If these foods are lost, there is then a need to purchase replacements which has additional associated costs related to travel time and cost. While 56.6% of respondents agreed with the tolerance statement "if the compensation scheme was improved (faster and more compensation) people would not get angry when elephants raid fields", 58.0% of respondents still agreed with the reverse tolerance statement regarding people still getting angry and killing an elephant suggesting improved compensation alone is unlikely to increase tolerance (Table S4.6). McNutt *et al.* (2017) found that reported lethal control was almost twice as likely in households denied compensation for livestock losses. However, 23% of households granted compensation still reported using lethal control. This suggests that compensation schemes alone are not enough to increase tolerance towards wildlife. By focussing on the quantifiable loss, the social context of the event is lost.

5.6 Conclusions

While compensation in certain scenarios can prove effective (Klenke *et al.* 2013; Tombre, Eythórsson & Madsen 2013), in the majority of situations this tends not to be the case (Madhusudan 2003; Jackson *et al.* 2008; Boitani, Ciucci & Raganella-Pelliccioni 2010; Ravenelle & Nyhus 2017). As compensation does not meet farmers' expectations, it is unlikely to be effective at increasing tolerance for wildlife damage. If a compensation scheme is to be continued, there needs to be dialogue between all stakeholders to determine what constitutes fair compensation. This not only includes which crops are compensated for, and the value of compensation, but the commitments farmers make to the government (including having suitable defences in place) and the commitments the government make to farmers in terms of attending crop-foraging events and the timely distribution of compensation. Until stakeholders reach agreement on this, conflict between stakeholders will continue.

Chapter 6. Discussion

6.1 Foreword

Human-wildlife interactions are complex, involving biological, social, economic and political factors and requiring interdisciplinary approaches to achieve coexistence (White & Ward 2010; Redpath *et al.* 2015). These interactions cannot be changed hastily and require detailed understanding of the interaction from both the wildlife and stakeholder's perspectives.

While modernisation may reduce the hazards posed by nature as people move from rural to urban areas, thereby improving attitudes towards wildlife and its conservation (Bruskotter *et al.* 2017), increasing human populations and reduced space for wildlife means interactions between people and wildlife are likely to continue. Negative interactions can have impacts upon both people and wildlife, and the situation is likely to deteriorate without management interventions. Conflicts between stakeholders over wildlife are increasing, often leading to increasingly polarised attitudes, with coexistence requiring much greater investment through resolution and reconciliation processes (Madden & McQuinn 2014; Jacobsen & Linnell 2016).

So far, studies have taken a parochial approach to interactions, as did I due to the time constraints on a PhD. My results apply to a small region where negative interactions are high and understanding these interactions is important. However, if management of interactions is to move forwards, practitioners need to rethink the issue and take a different, more holistic, approach. For many negative interactions, information is available on when, where and sometimes why interactions take place. Biological aspects of these interactions are relatively well understood and several promising mitigation strategies have been developed (chapter 1). However, applying this knowledge has had limited success in reducing human-wildlife interactions, ultimately due to our poor understanding of the human component and its multi-faceted complexity.

In this chapter, I will review the status of human-wildlife interactions in the context of my study and focus on where our understanding is limited and research should focus if we are to coexist with wildlife globally.

6.2 When, where and why interactions occur

Hitherto, human-wildlife interactions have typically been investigated from the biological perspective, providing conservationists and managers with knowledge on a wide variety of aspects to the interactions. For instance, the frequency of predator interactions are likely to increase when prey populations are depleted (Khorozyan *et al.* 2015) or during the wet season when prey are more dispersed (Valeix *et al.* 2012), foraging on crops occurs when crops ripen (Hillman-Smith *et al.* 1995), or natural forage quality declines (Osborn 2004). These temporal patterns are often uniform across multiple regions, and so provide stakeholders with general information on when interactions are likely to take place. Temporal patterns provide managers and practitioners with important information on when interactions between humans and elephants are likely to occur, both seasonally and in finer detail in relation to the lunar cycle. The seasonal patterns inform wildlife managers and practitioners when they should mobilise resources to assist farmers, while finer scale temporal patterns are useful for farmers themselves, to identify when guarding efforts should be increased to deter elephants from entering fields, minimising the direct and indirect costs of guarding and increasing their efficacy.

Spatial patterns have been harder to predict, varying between locations and at different spatial scales. At larger scales, interactions take place where humans and wildlife overlap, with distance to protected areas (Miller *et al.* 2015; Chen *et al.* 2016), density of wildlife (O'Connell-Rodwell *et al.* 2000) and human density (Guerbois, Chapanda & Fritz 2012) providing locations of interaction hotspots. Within these hotspots, spatial patterns have been harder to identify. For smaller bodied species, distance to forest boundary shows certain patterns (Hill

2000). However, for large species such as elephants that travel greater distances, such patterns are often not apparent (chapter 2). While my aim in chapter 2 was to provide farmers with a toolkit of information to assist them in actively deterring elephants or reducing the resulting damage, I could not identify spatial patterns to crop-foraging. All fields appeared to be vulnerable in the Makgadikgadi region, with the extent of damage related to the crops present.

Although I could not find spatial patterns to interactions, identifying that all fields were vulnerable to crop-foraging in an area is still useful. Proactive management approaches provide greater benefits than responding to negative interactions, especially for species whose range extends outside protected areas (Thouless *et al.* 2016; Durant *et al.* 2017). Identifying where interactions are frequent allows for appropriate land use planning. Land use planning is likely to play a key role in reducing the occurrence of future interactions and should include providing incentives for appropriate land use. In Botswana there are many incentives for farmers to plant subsistence crops but this can exacerbate interactions because farming can expand into inappropriate areas, resulting in low-input, low-risk farming (Gupta 2013). Land use planning should be a crucial component when working with species that are likely to interact negatively with people (Linnell *et al.* 2005; Songhurst, McClloch & Coulson 2016).

Identifying why some species are involved in interactions is often more difficult to determine and likely to vary locally. Some species might adapt to human-dominated landscapes, gaining better nutrition from human sources than wild forage (Merkle *et al.* 2013); others may be driven to interactions at times when natural resources are limited (Naughton-Treves *et al.* 1998; Odden, Nilsen & Linnell 2013; Khorozyan *et al.* 2015); some may just be competing with humans over a resource (Kloskowski 2005); and within species some may gain nutritional benefits over conspecifics (Chiyo *et al.* 2011b). In chapter 3 I show that demographics of African elephants can predict the probability that they will crop-forage and this supports the hypothesis that this is because male elephants try to attain peak reproductive status. While it could be argued that identifying when and where interactions take place are the only factors needed when managing interactions, management will always be based on prevention rather than identifying the root causes crucial for long term management plans unless we understand what drives these interactions. Similarly, understanding how wildlife move or adjust their demographics in human-dominated landscapes helps managers and practitioners understand how wildlife might perceive a landscape. Unlike other studies, elephants did not appear to perceive risk in human-dominated landscapes in the Makgadikgadi region, and their only adjustment was to forage in fields at night. However, they showed directed movement towards fields, suggesting that it was targeted movement rather than random, and once inside fields they optimised their foraging strategy in a highly nutritious resource.

One of the important aspects of my study was that it was a fine-detail study at a small spatial scale. My findings are useful for farmers working in my study area. In many studies there are research implementation gaps with one of the key aspects being the discordance in the spatial scales at which the data are collected and then implemented (Montgomery *et al.* 2018). By identifying patterns at the field level, my results were directly applicable to farmers in the region. Likewise, understanding the demographics of elephants in a national park allowed meaningful comparisons to be drawn with the elephants involved in crop-foraging events outside the MPNP to determine if certain demographics are more prone to crop-foraging. While former studies have investigated the demographics of crop-foraging elephants, comparing to a “natural” population ensures patterns identified are a result of crop-foraging and not just the demographics of elephants in the region. Studying a primarily bull population of elephants provided me with a unique opportunity to identify patterns and behaviours in the absence of female elephants.

By recording fine detail damage data from crop-foraging events it became apparent that elephants did not select some crops more than others in the study region and movement within different crops did not differ, supporting this finding. Quantifying damage that had been caused through browsing and trampling assisted in determining if elephants “selected” for certain crops, which previous studies have often asserted based on general damage in fields or the apparent targeting of fields with certain crops. If practitioners are to suggest which crops farmers should plant, this should be based on accurate evidence, especially when implementation will affect human livelihoods.

6.3 Current status of management strategies

Based on biological aspects of human-wildlife interactions, primarily when and where interactions are likely to take place, strategies have been developed to deter interactions, from keeping wildlife out of certain areas (beehive fence; King *et al.* 2009; chilli fence; Chelliah *et al.* 2010; predator-proof boma; Lichtenfeld, Trout & Kisimir 2015) to various guarding practices (livestock guarding dogs; Marker, Dickman & Macdonald 2005). These strategies have been developed to reduce the frequency of interactions and the resulting impacts upon farmers. If this is not possible, policies may be in place to alleviate the financial burden through compensation or insurance schemes (Nyhus *et al.* 2005; Chen *et al.* 2013), or to provide revenue sharing initiatives from wildlife (Archabald & Naughton-Treves 2001). These approaches are often suggested as ways to help humans and wildlife coexist. However, when properly evaluated, the success of these projects is often limited (Hedges & Giunaryadi 2010; Eklund *et al.* 2017; McNutt *et al.* 2017). While compensating farmers for damage to crops may appear a simple solution, differences in damage estimates between farmers and government officials in relation to a compensation strategy, or perception of damage, results in the scheme being ineffective and likely to exacerbate social conflict (chapter 5). Detailed damage estimates in this study highlighted overestimates of perceived damage by farmers, with government compensation methods also overestimating values of damage. Previously, comparisons have been made between farmers’ perceptions and government compensation to identify differences. Identifying which aspects of valuing damage in a field causes differences between these groups helps to determine why disparities exist and how this can be addressed. In the Makgadikgadi region, uncompensated crops and farmer perception influenced differences and so discussion between stakeholders regarding the compensation strategy and assessment of damage may prove useful in determining a process acceptable to all parties.

Although mitigation strategies for human-wildlife interactions have shown positive results (Davies *et al.* 2011; Zarco-Gonzalez & Monroy-Vilchis 2014; Pozo *et al.* 2017; van Eeden *et al.* 2018), it is essential to test the efficacy of them in different areas. An approach that may work in one region can be ineffective in another, exacerbating the conflict between stakeholders and resulting in loss of trust. For example, beehive fences reduce the entry of elephants into fields in Kenya (King *et al.* 2009) but the lack of natural bee colonies in Botswana meant that hives were not colonised, resulting in no reduction in crop-foraging events (personal observation). Likewise, some strategies can go “viral”, such as the use of unmanned drones to haze elephants out of human-dominated areas, with perceptions that this can be used to scare elephants from fields, but conditions on the ground often make this impractical (Hahn *et al.* 2017). There is a need for conservation strategies to be evidence-based, especially when human livelihoods are at stake, as is the case with human-wildlife interactions (Sutherland *et al.* 2004).

Project design is increasingly being identified as the major factor for project success, irrespective of the management strategy being utilised. Projects with community ownership over design and management are found to be much more effective than top down project approaches (Zimmermann *et al.* 2009; Redpath *et al.* 2017). Individual communities will have a better understanding of what management strategy is likely to be effective, and so account for local factors that determine the success of projects. Organisations should focus less on the management/mitigation strategy and more on developing and implementing the strategy with community involvement, thereby making it locally appropriate. This may require a longer timeframe to implement but is likely to have a greater chance of success and sustainability

(Zimmermann *et al.* 2009). It should also be considered that a community's goals may be very different from a manager's. For example, after a "bottom-up" consultative framework, Harihar, Verissimo & MacMillan (2015) found that communities preferred not to coexist with tigers *Panthera tigris* and chose resettlement options. If practitioners had tried to develop a strategy involving coexistence, it may not have been successful.

6.4 The human component

It might be anticipated that management of human-wildlife interactions would be successful by understanding when and where interactions are going to take place and ensuring that effective resources are available to deter interactions. However, when management strategies have been evaluated, be it mitigation measures, compensation or even educational methods, success is often limited, with an overarching aspect being the lack of understanding of the human component (Webber, Hill & Reynolds 2007; Gore *et al.* 2008; McNutt *et al.* 2017). Management strategies always involve a human component. It could be the need for stakeholders to modify farming practices (Gross, McRobb & Gross 2016), maintain mitigation strategies (Osborn & Parker 2003) or adjust behaviours (Baruch-Mordo *et al.* 2011; Penteriani *et al.* 2016). What might be perceived as simple adjustments for the benefit of the stakeholder are often not completed or not completed correctly, resulting in no benefit. This frequently leaves practitioners confused about the seriousness of interactions for the affected stakeholder(s). It is the human component that requires further research and understanding if we are to manage human-wildlife interactions successfully. This would not only be applicable to human-wildlife interactions but many wider conservation issues such as climate change and pollution where pro-environmental behaviours are required for successful outcomes.

A simple understanding of human-wildlife interactions is that the level of damage caused by wildlife is directly related to the level of "conflict", the response is proportionate to the level of "conflict" and that altering the response to "conflict" will have proportionate conservation effects (reported by Dickman 2010). However, this is almost never the case. Factors such as values and beliefs influence the intensity of interactions, meaning that these relationships are seldom proportional. We are often only able to measure the direct costs of interactions. However, it is becoming clearer that indirect costs are likely to have a greater influence and therefore need addressing (chapter 4). Although negative interactions with wildlife influenced farmers' attitudes in my study, the direct costs did not seem to be a major component (chapter 4). Farmers may not experience negative interactions themselves but still suffer indirect costs due to the presence of wildlife. Acknowledging and addressing these indirect costs is likely to help influence attitudes towards wildlife.

Furthermore, when addressing the conflict between stakeholders, it might appear that the conflict is over the impact wildlife has on people and *vice versa*, and so technical fixes should resolve the conflict. However, research from the peacebuilding sector suggests that this is merely the tip of the visible "iceberg" and that below the surface other factors are influencing the social conflicts (Madden & McQuinn 2014). Without addressing these complex social conflicts, current efforts to engage stakeholders and address visible impacts are likely to be unsuccessful and may even escalate the situation. When projects have not been successful, it has often been due to poor uptake of technical fixes that should reduce visible impacts (Webber, Hill & Reynolds 2007; Graham & Ochieng 2008). Studying the different levels of conflict often identifies social conflicts that need to be addressed properly if technical fixes are to be addressed. For example, in the Makgadikgadi region there was very little uptake of mitigation strategies to deter elephants from fields even though equipment and training were provided at no cost by the World Bank and DWNP. At the dispute level, social conflict was over the entry of elephants into fields, and the resulting conflict between farmers and the DWNP. However, there were often many other unresolved disputes discussed regarding access to natural resources, compensation and land rights that might have caused underlying social conflict. Resentment regarding these disputes may exacerbate the current dispute (elephants in fields). The identity of stakeholders can also result in a deeper level of social conflict, involving deep-rooted values, needs and beliefs. It might be perceived that one group's identity is completely at odds to another group's and therefore causes perceived threats. Conservationists' resources are often directed at securing a future for wildlife: local communities might perceive conservationists' objectives as negatively affecting their own livelihoods. Local communities may not trust conservationists and their motives, and so actively avoid engagement with strategies that may improve their livelihoods. So, projects are unlikely to succeed without addressing the social conflicts that are often not visible or even discussed. Resolution between stakeholders is required to resolve underlying conflicts, while reconciliation is needed for identity-based conflicts. It is these conflicts that are often not identified or addressed when managing human-wildlife interactions but organisations need to focus on these aspects if coexistence with wildlife is to be achieved and social conflicts reduced.

Finally, for these strategies to be effective, managers and practitioners need to plan projects over longer time periods, rather than the time constraints imposed by funding restrictions (Webber, Hill & Reynolds 2007). While behaviours and attitudes are unlikely to change quickly, researchers are frequently expected to report success of projects after short periods of time, even though this is often not feasible. Objectives tend to be based on attitude change or achievement of deliverables (Veríssimo 2013). Attitudes can change, and materials can be delivered, suggesting successful projects. However, unless behaviours change, and materials are used correctly and effectively, these factors will most probably result in false indicators of success and can be detrimental to the overall project. Success should be based on long term behaviour change, reductions in interactions and, most importantly reductions in social conflicts.

6.5 Future work

While biological questions remain unanswered in many human-wildlife interaction scenarios and research into these should be pursued (as discussed in chapters 2 and 3), knowledge of managing interactions and the human component is limited but essential if humans are to successfully coexist with wildlife. Therefore, below I provide suggestions for future research to address some of the challenges faced by conservation practitioners to ensure that strategies are effective.

In many human-wildlife interaction situations, proposed management practices often involve a stakeholder needing to change their behaviour. Farmers may need to increase their guarding effort in fields at night to deter elephants (chapters 2 and 3). Farmers can be informed about the need to do this, and understand why this should be done, but this does not necessarily result in behaviours changing. While it may be possible to change attitudes and intention, changing behaviour can be difficult (Gore *et al.* 2008; Itzchakov, Uziel & Wood 2018). Previously, attitudes and intentions have been assessed as a proxy for behaviour change, although changes in behaviour are rarely investigated (Gore *et al.* 2008). This can lead to situations where stakeholders may appear committed to scientifically proven management practices but do not necessarily complete the required actions (Pooley *et al.* 2017). Understanding why some individuals change their behaviour and whether factors such as habit, lack of resources or the degree of effort involved influence behavioural decisions will be crucial in the management stage of mitigating interactions. Likewise, ensuring that projects are evaluated using behaviour change rather than attitude changes will provide a greater indicator of their success or failure.

If mitigation strategies and management of human-wildlife interactions are to be evaluated and perceived effective, one aspect is the reduction in the frequency of negative interactions. A farmer successfully implementing a strategy might perceive success if they incur fewer negative interactions. While this is important, it is also important to determine whether the scale of interactions have been reduced across a village or even a region. While on-farm mitigation strategies may deter interactions for one farmer, the effect on other farmers is often unknown. So while lethal control of wolves had potentially beneficial effects locally in relation to depredation events, this was offset by detrimental effects for neighbouring farms (Santiago-Avila, Cornman & Treves 2018). Likewise, the use of deterrents decreased the incidences of crop-foraging and crop loss by primates in Uganda but shifted the behaviour to unprotected fields (Hill & Wallace 2012). It is therefore important to assess whether there is a net loss in the frequency of negative interactions or whether interactions are displaced to farms without mitigation when determining the success of a strategy across a region.

Finally, even if human-wildlife interactions are understood and stakeholders are willing to apply mitigation strategies effectively, one of the next issues is how to upscale projects. While governments often fund top down strategies such as fencing off areas of land or providing compensation for wildlife damage, on-farm mitigation often involves farmers inputting resources for mitigation themselves or NGOs supporting them through financial aid or the purchase of equipment. In Tanzania, farmer-to-farmer exchanges introduced the concept of chilli fences rapidly, while the support from community-based organisations ensured that programs were sustainable (Chang'a *et al.* 2016). This can work well where NGOs are active. However, there are substantial spatial gaps in areas where organisations are not present, resulting in farmers not receiving training or equipment. Therefore, there is a need for increased awareness and uptake of effective mitigation strategies (Chang'a *et al.* 2016). Addressing the scale of conflict mitigation is a fundamental challenge for many conservation interventions (Mascia & Mills 2018). Understanding how to upscale these community-based projects to other regions, while accounting for local variability in the interaction dynamic, is essential if success is to be achieved on a global scale. Research into which mitigation strategies are likely to spread, who is likely to adopt strategies and how different geographical, cultural and policy contexts influence diffusion of strategies is likely to be influential at scaling up strategies and ensuring longer-lasting successful impacts (Mascia & Mills 2018).

6.6 Concluding remarks

Human-wildlife interactions will continue to be present globally as human and wildlife populations expand and overlap. Understanding the biological components of these interactions will continue to be important in identifying when, where and why interactions take place. However, if humans are to live alongside wildlife, conservationists need to understand the negative interactions in much greater depth, not just at the impact level. While understanding human-wildlife interactions from the wildlife's perspective is important, it is the actions of humans that will bring about coexistence.

References

Acemoglu, D., Johnson, S. & Robinson, J. (2001) An African success story: Botswana. *Working Paper No. 01-37*. MIT Department of Economics.

Adams, T.S., Chase, M.J., Attard, A. & Leggett, K.E. (2017) A preliminary study of stakeholders' opinions and perceptions of elephants and elephant management in Botswana. *Pachyderm,* **58,** 67-76.

Ahlering, M.A., Millspaugh, J.J., Woods, R.J., Western, D. & Eggert, L.S. (2011) Elevated levels of stress hormones in crop-raiding male elephants. *Animal Conservation,* **14,** 124-130.

Ainsley, M. & Kosoy, N. (2015) The tragedy of bird scaring. *Ecological Economics,* **116,** 122-131.

Allan, R. (1996) *The grain-eating birds of sub-Saharan Africa: identification, biology and management*. Natural Resources Institute, Chatham, UK.

Ango, T.G., Börjeson, L. & Senbeta, F. (2017) Crop raiding by wild mammals in Ethiopia: impacts on the livelihoods of smallholders in an agriculture–forest mosaic landscape. *Oryx,* **51,** 527-537.

Archabald, K. & Naughton-Treves, L. (2001) Tourism revenue-sharing around national parks in western Uganda: early efforts to identify and reward local communities. *Environmental Conservation,* **28,** 135-149.

Archie, E.A., Moss, C.J. & Alberts, S.C. (2006) The ties that bind: genetic relatedness predicts the fission and fusion of social groups in wild African elephants. *Proceedings of the Royal Society B: Biological Sciences,* **273,** 513-522.

Bal, P., Nath, C.D., Nanaya, K.M., Kushalappa, C.G. & Garcia, C. (2011) Elephants also like coffee: trends and drivers of human-elephant conflicts in coffee agroforestry landscapes of Kodagu, Western Ghats, India. *Environmental Management,* **47,** 789-801.

Bandara, R. & Tisdell, C. (2002) Asian elephants as agricultural pests: economics of control and compensation in Sri Lanka. *Natural Resources Journal,* **42,** 491-519.

Bandara, R. & Tisdell, C. (2003) Comparison of rural and urban attitudes to the conservation of Asian elephants in Sri Lanka: empirical evidence. *Biological Conservation,* **110,** 327-342.

Barnes, R.F.W. (1996) The conflict between humans and elephants in the central African forests. *Mammal Review,* **26,** 67-80.

Barnes, R.F.W., Dubiure, U.F., Danquah, E., Boafo, Y., Nandjui, A., Hema, E.M. & Manford, M. (2007) Crop-raiding elephants and the moon. *African Journal of Ecology,* **45,** 112-115.

Barnes, R.F.W., Hema, E.M., Nandjui, A., Manford, M., Dubiure, U.F., Danquah, E.K.A. & Boafo, Y. (2005) Risk of crop raiding by elephants around the Kakum Conservation Area, Ghana. *Pachyderm,* **39,** 19-25.

Barnosky, A.D., Hadly, E.A., Bascompte, J., Berlow, E.L., Brown, J.H., Fortelius, M., Getz, W.M., Harte, J., Hastings, A., Marquet, P.A., Martinez, N.D., Mooers, A., Roopnarine, P., Vermeij, G., Williams, J.W., Gillespie, R., Kitzes, J., Marshall, C., Matzke, N., Mindell, D.P., Revilla, E. & Smith, A.B. (2012) Approaching a state shift in Earth's biosphere. *Nature,* **486,** 52-58.

Barua, M., Bhagwat, S.A. & Jadhav, S. (2013) The hidden dimensions of human-wildlife conflict: health impacts, opportunity and transaction costs. *Biological Conservation,* **157,** 309-316.

Baruch-Mordo, S., Breck, S.W., Wilson, K.R. & Broderick, J. (2011) The carrot or the stick? Evaluation of education and enforcement as management tools for human-wildlife conflicts. *Plos One,* **6,** e15681.

Bates, D., Mächler, M., Bolker, B. & Walker, S. (2015) Fitting linear mixed-effects models using lme4. *Journal of Statistical Software,* **67,** 1-48.

Bath, A.J. (1998) The role of human dimensions in wildlife resource research in wildlife management. *Ursus,* **10,** 349-355.

Batisani, N. & Yarnal, B. (2010) Rainfall variability and trends in semi-arid Botswana: implications for climate change adaptation policy. *Applied Geography,* **30,** 483-489.

Bayani, A., Tiwade, D., Dongre, A., Dongre, A. P., Phatak, R. and Watve, M. (2016) Assessment of crop damage by protected wild mammalian herbivores on the western boundary of Tadoba-Andhari Tiger Reserve (TATR), central India. *Plos One,* **11,** e0153854.

Benhamou, S. & Bovet, P. (1989) How animals use their environment: a new look at kinesis. *Animal Behaviour,* **38,** 375-383.

Bhima, R. (1998) Elephant status and conflict with humans on the western bank of Liwonde National Park, Malawi. *Pachyderm,* **25,** 74-80.

Blackwell, B.F., DeVault, T.L., Fernandez-Juricic, E., Gese, E.M., Gilbert-Norton, L. & Breck, S.W. (2016) No single solution: application of behavioural principles in mitigating human-wildlife conflict. *Animal Behaviour,* **120,** 245-254.

Blake, S. & Inkamba-Nkulu, C. (2004) Fruit, minerals, and forest elephant trails: do all roads lead to Rome? *Biotropica,* **36,** 392-401.

Blanc, J.J. (2008) *Loxodonta africana*. The IUCN Red List of Threatened Species 2008: e.T12392A3339343. Access date: 19/05/18.

Boast, L., Houser, A., Horgan, J., Reeves, H., Phale, P. & Klein, R. (2016) Prey preferences of free-ranging cheetahs on farmland: scat analysis versus farmers' perceptions. *African Journal of Ecology,* **54,** 424-433.

Boitani, L., Ciucci, P. & Raganella-Pelliccioni, E. (2010) Ex-post compensation payments for wolf predation on livestock in Italy: a tool for conservation? *Wildlife Research,* **37,** 722-730.

Bond, W.J. (1994) Keystone species. *Biodiversity and ecosystem function* (eds E.D. Schulze & H.A. Mooney), pp. 237-253. Springer Berlin Heidelberg, Berlin, Heidelberg.

Brooks, C. & Bradley, J. (2010) Fences in Botswana: every fence should be judged on its own merits. *Fencing impacts: a review of the environmental, social and economic impacts of game and veterinary fencing in Africa with particular reference to the Great Limpopo and Kavango-Zambezi Transfrontier Conservation Areas* (eds K. Ferguson & J. Hanks), pp. 128-133. Mammal Research Institute, Pretoria, South Africa.

Brooks, C.J. (2005) The foraging behaviour of Burchell's zebra (*Equus burchelli antiquorum)*. PhD, University of Bristol.

Bruskotter, J.T., Vucetich, J.A., Manfredo, M.J., Karns, G.R., Wolf, C., Ard, K., Carter, N.H., López-Bao, J.V., Chapron, G., Gehrt, S.D. & Ripple, W.J. (2017) Modernization, risk, and conservation of the world's largest carnivores. *Bioscience,* **67,** 646-655.

Bulte, E.H. & Rondeau, D. (2005) Why compensating wildlife damages may be bad for conservation. *Journal of Wildlife Management,* **69,** 14-19.

Burbidge, A.A. & Woinarski, J. (2016) *Thylacinus cynocephalus.* The IUCN Red List of Threatened Species 2016: e.T21866A21949291. Access date: 23/02/18.

Burnham, K.P. & Anderson, D.R. (1998) *Model selection and multimodel inference: a practical information-theoretic approach,* 2nd edn. Springer, New York.

Campbell-Smith, G., Simanjorang, H.V.P., Leader-Williams, N. & Linkie, M. (2010) Local attitudes and perceptions toward crop-raiding by orangutans (*Pongo abelii*) and other nonhuman primates in northern Sumatra, Indonesia. *American Journal of Primatology,* **72,** 866-876.

Carter, N.H., Riley, S.J., Shortridge, A., Shrestha, B.K. & Liu, J. (2014) Spatial assessment of attitudes toward tigers in Nepal. *Ambio,* **43,** 125-137.

Caughley, G. (1976) The elephant problem–an alternative hypothesis. *African Journal of Ecology,* **14,** 265-283.

Caughley, G., Dublin, H. & Parker, I. (1990) Projected decline of the African elephant. *Biological Conservation,* **54,** 157-164.

Chamberlain, A.L. (2016) An analysis of the human elephant conflict situation in the Boteti area, Botswana: the economic cost of elephant crop raiding. MRes, University of Bristol.

Chang'a, A., de Souza, N., Muya, J., Keyyu, J., Mwakatobe, A., Malugu, L., Ndossi, H.P., Konuche, J., Omondi, R., Mpinge, A., Hahn, N., Palminteri, S. & Olson, D. (2016) Scaling-up the use of chili fences for reducing human-elephant conflict across landscapes in Tanzania. *Tropical Conservation Science,* **9,** 921-930.

Chase, M. (2011) Dry season fixed-wing aerial survey of elephants and wildlife in northern Botswana, September-November 2010. Elephants Without Borders, Kasane, Botswana.

Chase, M., Schlossberg, S., Landen, K., Sutcliffe, R., Seonyatseng, E., Keitsile, A. & Flyman, M. (2015) Dry season aerial survey of elephants and wildlife in northern Botswana: July-October 2014. Elephants Without Borders, the Department of Wildlife and National Parks (Botswana), Great Elephant Census.

Chase, M.J., Schlossberg, S., Griffin, C.R., Bouché, P.J.C., Djene, S.W., Elkan, P.W., Ferreira, S., Grossman, F., Kohi, E.M., Landen, K., Omondi, P., Peltier, A., Selier, S.A.J. & Sutcliffe, R. (2016) Continent-wide survey reveals massive decline in African savannah elephants. *Peerj,* **4,** e2354.

Chelliah, K., Kannan, G., Kundu, S., Abilash, N., Madhusudan, A., Baskaran, N. & Sukumar, R. (2010) Testing the efficacy of a chilli-tobacco rope fence as a deterrent against crop-raiding elephants. *Current Science,* **99,** 1239-1243.

Chen, S., Yi, Z.F., Campos-Arceiz, A., Chen, M.Y. & Webb, E.L. (2013) Developing a spatially-explicit, sustainable and risk-based insurance scheme to mitigate human-wildlife conflict. *Biological Conservation,* **168,** 31-39.

Chen, Y., Marino, J., Tao, Q., Sullivan, C.D., Shi, K. & Macdonald, D.W. (2016) Predicting hotspots of human-elephant conflict to inform mitigation strategies in Xishuangbanna, southwest China. *Plos One,* **11,** e0162035.

Chiyo, P.I., Archie, E.A., Hollister-Smith, J.A., Lee, P.C., Poole, J.H., Moss, C.J. & Alberts, S.C. (2011a) Association patterns of African elephants in all-male groups: the role of age and genetic relatedness. *Animal Behaviour,* **81,** 1093-1099.

Chiyo, P.I. & Cochrane, E.P. (2005) Population structure and behaviour of crop-raiding elephants in Kibale National Park, Uganda. *African Journal of Ecology,* **43,** 233-241.

Chiyo, P.I., Cochrane, E.P., Naughton, L. & Basuta, G.I. (2005) Temporal patterns of crop raiding by elephants: a response to changes in forage quality or crop availability? *African Journal of Ecology,* **43,** 48-55.

Chiyo, P.I., Lee, P.C., Moss, C.J., Archie, E.A., Hollister-Smith, J.A. & Alberts, S.C. (2011b) No risk, no gain: effects of crop raiding and genetic diversity on body size in male elephants. *Behavioral Ecology,* **22,** 552-558.

Chiyo, P.I., Moss, C.J. & Alberts, S.C. (2012) The influence of life history milestones and association networks on crop-raiding behavior in male African elephants. *Plos One,* **7,** e31382.

Chiyo, P.I., Moss, C.J., Archie, E.A., Hollister-Smith, J.A. & Alberts, S.C. (2011c) Using molecular and observational techniques to estimate the number and raiding patterns of crop-raiding elephants. *Journal of Applied Ecology,* **48,** 788-796.

Chiyo, P.I., Wilson, J.W., Archie, E.A., Lee, P.C., Moss, C.J. & Alberts, S.C. (2014) The influence of forage, protected areas, and mating prospects on grouping patterns of male elephants. *Behavioral Ecology,* **25,** 1494-1504.

Dai, X., Shannon, G., Slotow, R., Page, B. & Duffy, K.J. (2007) Short-duration daytime movements of a cow herd of African elephants. *Journal of Mammalogy,* **88,** 151-157.

Davies, T.E., Wilson, S., Hazarika, N., Chakrabarty, J., Das, D., Hodgson, D.J. & Zimmermann, A. (2011) Effectiveness of intervention methods against crop-raiding elephants. *Conservation Letters,* **4,** 346-354.

de Boer, W.F. & Baquete, D.S. (1998) Natural resource use, crop damage and attitudes of rural people in the vicinity of the Maputo Elephant Reserve, Mozambique. *Environmental Conservation,* **25,** 208-218.

de Boer, W.F., Ntumi, C.P., Correia, A.U. & Mafuca, J.M. (2000) Diet and distribution of elephant in the Maputo Elephant Reserve, Mozambique. *African Journal of Ecology,* **38,** 188-201.

de Knegt, H.J., Hengeveld, G.M., van Langevelde, F., de Boer, W.F. & Kirkman, K.P. (2007) Patch density determines movement patterns and foraging efficiency of large herbivores. *Behavioral Ecology,* **18,** 1065-1072.

DeMotts, R. & Hoon, P. (2012) Whose elephants? Conserving, compensating, and competing in northern Botswana. *Society & Natural Resources,* **25,** 837-851.

Department of Environmental Affairs and Centre for Applied Research (2010) The Makgadikgadi Framework Management Plan. Government of Botswana, Gaborone.

Dhamorikar, A.H., Mehta, P., Bargali, H. & Gore, K. (2017) Characteristics of human - sloth bear (*Melursus ursinus*) encounters and the resulting human casualties in the Kanha-Pench corridor, Madhya Pradesh, India. *Plos One,* **12,** e0176612.

Dickman, A.J. (2010) Complexities of conflict: the importance of considering social factors for effectively resolving human-wildlife conflict. *Animal Conservation,* **13,** 458-466.

Dickman, A.J., Macdonald, E.A. & Macdonald, D.W. (2011) A review of financial instruments to pay for predator conservation and encourage human-carnivore coexistence. *Proceedings of the National Academy of Sciences of the United States of America,* **108,** 13937-13944.

Dickson, B.G., Jenness, J.S. & Beier, P. (2005) Influence of vegetation, topography, and roads on cougar movement in southern California. *Journal of Wildlife Management,* **69,** 264-276.

Douglas-Hamilton, I. (1972) On the ecology and behaviour of the African elephant. D. Phil Thesis, University of Oxford, UK.

Douglas-Hamilton, I. (1987) African elephants: population trends and their causes. *Oryx,* **21,** 11-24.

Douglas-Hamilton, I., Krink, T. & Vollrath, F. (2005) Movements and corridors of African elephants in relation to protected areas. *Naturwissenschaften,* **92,** 158-163.

Dudley, J.P., Mensah-Ntiamoah, A.Y. & Kpelle, D.G. (1992) Forest elephants in a rainforest fragment: preliminary findings from a wildlife conservation project in southern Ghana. *African Journal of Ecology,* **30,** 116-126.

Duffy, K.J., Dai, X., Shannon, G., Slotow, R. & Page, B. (2011) Movement patterns of African elephants (*Loxodonta africana*) in different habitat types. *South African Journal of Wildlife Research,* **41,** 21-28.

Durant, S.M., Mitchell, N., Groom, R., Pettorelli, N., Ipavec, A., Jacobson, A.P., Woodroffe, R., Böhm, M., Hunter, L.T.B., Becker, M.S., Broekhuis, F., Bashir, S., Andresen, L., Aschenborn, O., Beddiaf, M., Belbachir, F., Belbachir-Bazi, A., Berbash, A., Brandao de Matos Machado, I., Breitenmoser, C., Chege, M., Cilliers, D., Davies-Mostert, H., Dickman, A.J., Ezekiel, F., Farhadinia, M.S., Funston, P., Henschel, P., Horgan, J., de Iongh, H.H., Jowkar, H., Klein, R., Lindsey, P.A., Marker, L., Marnewick, K., Melzheimer, J., Merkle, J., soka, J., Msuha, M., Neill, H., Parker, M., Purchase, G., Sahailou, S., Saidu, Y., Samna, A., Schmidt-Küntzel, A., Selebatso, E., Sogbohossou, E.A., Soultan, A., Stone, E., van der Meer, E., van Vuuren, R., Wykstra, M. & Young-Overton, K. (2017) The global decline of cheetah *Acinonyx jubatus* and what it means for conservation. *Proceedings of the National Academy of Sciences,* **114,** 528-533.

DWNP (2012) Aerial census of animals in Botswana: 2012 dry season. Department of Wildlife and National Parks, Gaborone. Botswana.

Eggert, L.S., Rasner, C.A. & Woodruff, D.S. (2002) The evolution and phylogeography of the African elephant inferred from mitochondrial DNA sequence and nuclear microsatellite markers. *Proceedings of the Royal Society of London. Series B: Biological Sciences,* **269,** 1993-2006.

Eklund, A., López-Bao, J.V., Tourani, M., Chapron, G. & Frank, J. (2017) Limited evidence on the effectiveness of interventions to reduce livestock predation by large carnivores. *Scientific Reports,* **7,** 2097.

Elfstrom, M., Davey, M.L., Zedrosser, A., Muller, M., De Barba, M., Stoen, O.G., Miquel, C., Taberlet, P., Hacklander, K. & Swenson, J.E. (2014) Do Scandinavian brown bears approach settlements to obtain high-quality food? *Biological Conservation,* **178,** 128-135.

Ericsson, G. & Heberlein, T.A. (2003) Attitudes of hunters, locals, and the general public in Sweden now that the wolves are back. *Biological Conservation,* **111,** 149-159.

Eriksson, M., Sandström, C. & Ericsson, G. (2015) Direct experience and attitude change towards bears and wolves. *Wildlife Biology,* **21,** 131-137.

Evans, L.A. & Adams, W.M. (2016) Fencing elephants: the hidden politics of wildlife fencing in Laikipia, Kenya. *Land Use Policy,* **51,** 215-228.

Frank, L.G., Woodroffe, R. & Ogada, M.O. (2005) People and predators in Laikipia District, Kenya. *People and wildlife, conflict or co-existence?* (eds A. Rabinowitz, R. Woodroffe & S. Thirgood), pp. 286-304. Cambridge University Press, Cambridge.

Gadd, M. (2003) Elephant ecology and conservation in African rangelands. PhD, University of California at Davis.

Gadd, M.E. (2005) Conservation outside of parks: attitudes of local people in Laikipia, Kenya. *Environmental Conservation,* **32,** 50-63.

Garriga, R.M., Marco, I., Casas-Díaz, E., Amarasekaran, B. & Humle, T. (2017) Perceptions of challenges to subsistence agriculture, and crop foraging by wildlife and chimpanzees *Pan troglodytes verus* in unprotected areas in Sierra Leone. *Oryx***,** 1-14.

Gillingham, S. & Lee, P.C. (2003) People and protected areas: a study of local perceptions of wildlife crop-damage conflict in an area bordering the Selous Game Reserve, Tanzania. *Oryx,* **37,** 316-325.

Goodrich, J.M., Seryodkin, I.V., Miquelle, D.G., Kerley, L.L., Quigley, H.B. & Hornocker, M.G. (2011) Effects of canine breakage on tiger survival, reproduction and human-tiger conflict. *Journal of Zoology,* **285,** 93-98.

Gore, M.L., Knuth, B.A., Scherer, C.W. & Curtis, P.D. (2008) Evaluating a conservation investment designed to reduce human-wildlife conflict. *Conservation Letters,* **1,** 136-145.

Graham, M.D., Douglas-Hamilton, I., Adams, W.M. & Lee, P.C. (2009a) The movement of African elephants in a human-dominated land-use mosaic. *Animal Conservation,* **12,** 445-455.

Graham, M.D., Gichohi, N., Kamau, F., Aike, G., Craig, B., Douglas-Hamilton, I. & Adams, W.M. (2009b) The use of electrified fences to reduce human elephant conflict: a case study of the Ol Pejeta Conservancy, Laikipia District, Kenya, Working Paper 1, Laikipia Elephant Project, Nanyuki, Kenya.

Graham, M.D., Notter, B., Adams, W.M., Lee, P.C. & Ochieng, T.N. (2010) Patterns of crop-raiding by elephants, *Loxodonta africana*, in Laikipia, Kenya, and the management of human-elephant conflict. *Systematics and Biodiversity,* **8,** 435-445.

Graham, M.D. & Ochieng, T. (2008) Uptake and performance of farm-based measures for reducing crop raiding by elephants *Loxodonta africana* among smallholder farms in Laikipia District, Kenya. *Oryx,* **42,** 76-82.

Groom, R. & Harris, S. (2008) Conservation on community lands: the importance of equitable revenue sharing. *Environmental Conservation,* **35,** 242-251.

Gross, E.M., McRobb, R. & Gross, J. (2016) Cultivating alternative crops reduces crop losses due to African elephants. *Journal of Pest Science,* **89,** 497-506.

Gubbi, S. (2012) Patterns and correlates of human-elephant conflict around a south Indian reserve. *Biological Conservation,* **148,** 88-95.

Guerbois, C., Chapanda, E. & Fritz, H. (2012) Combining multi-scale socio-ecological approaches to understand the susceptibility of subsistence farmers to elephant crop raiding on the edge of a protected area. *Journal of Applied Ecology,* **49,** 1149-1158.

Gunn, J., Hawkins, D., Barnes, R.F.W., Mofulu, F., Grant, R.A. & Norton, G.W. (2014) The influence of lunar cycles on crop-raiding elephants; evidence for risk avoidance. *African Journal of Ecology,* **52,** 129-137.

Gupta, A.C. (2013) Elephants, safety nets and agrarian culture: understanding human-wildlife conflict and rural livelihoods around Chobe National Park, Botswana. *Journal of Political Ecology,* **20,** 238-254.

Gurung, B.B. (2008) Ecological and sociological aspects of human-tiger conflicts in Chitwan National Park, Nepal. PhD, University of Minnesota.

Hahn, N., Mwakatobe, A., Konuche, J., de Souza, N., Keyyu, J., Goss, M., Chang'a, A., Palminteri, S., Dinerstein, E. & Olson, D. (2017) Unmanned aerial vehicles mitigate human–elephant conflict on the borders of Tanzanian parks: a case study. *Oryx,* **51,** 513-516.

Harihar, A., Verissimo, D. & MacMillan, D.C. (2015) Beyond compensation: integrating local communities' livelihood choices in large carnivore conservation. *Global Environmental Change-Human and Policy Dimensions,* **33,** 122-130.

Hay, C.T., Cross, P.C. & Funston, P.J. (2008) Trade-offs of predation and foraging explain sexual segregation in African buffalo. *Journal of Animal Ecology,* **77,** 850-858.

Hazzah, L., Bath, A., Dolrenry, S., Dickman, A. & Frank, L. (2017) From attitudes to actions: predictors of lion killing by Maasai warriors. *Plos One,* **12,** e0170796.

Heberlein, T.A. (2012) Navigating environmental attitudes. *Conservation Biology,* **26,** 583-585.

Hedges, S. & Giunaryadi, D. (2010) Reducing human-elephant conflict: do chillies help deter elephants from entering crop fields? *Oryx,* **44,** 139-146.

Hemson, G. (2003) The ecology and conservation of lions: human-wildlife conflict in semi-arid Botswana. PhD, University of Oxford.

Hemson, G., Maclennan, S., Mills, G., Johnson, P. & Macdonald, D. (2009) Community, lions, livestock and money: a spatial and social analysis of attitudes to wildlife and the conservation value of tourism in a human-carnivore conflict in Botswana. *Biological Conservation,* **142,** 2718-2725.

Hill, C.M. (1998) Conflicting attitudes towards elephants around the Budongo Forest Reserve, Uganda. *Environmental Conservation,* **25,** 244-250.

Hill, C.M. (2000) Conflict of interest between people and baboons: crop raiding in Uganda. *International Journal of Primatology,* **21,** 299-315.

Hill, C.M. (2004) Farmers' perspectives of conflict at the wildlife–agriculture boundary: some lessons learned from African subsistence farmers. *Human Dimensions of Wildlife,* **9,** 279-286.

Hill, C.M. (2017a) Crop raiding. *The international encyclopedia of primatology*. John Wiley & Sons, Inc.

Hill, C.M. (2017b) Primate crop feeding behavior, crop protection, and conservation. *International Journal of Primatology,* **38,** 385-400.

Hill, C.M. & Wallace, G.E. (2012) Crop protection and conflict mitigation: reducing the costs of living alongside non-human primates. *Biodiversity and Conservation,* **21,** 2569-2587.

Hill, R.A. & Lee, P.C. (1998) Predation risk as an influence on group size in cercopithecoid primates: implications for social structure. *Journal of Zoology,* **245,** 447-456.

Hillman-Smith, A.K.K., de Merode, E., Nicholas, A., Buls, B. & Ndey, A. (1995) Factors affecting elephant distribution at Garamba National Park and surrounding reserves, Zaire, with a focus on human-elephant conflict. *Pachyderm,* **19,** 39-48.

Hoare, R.E. (1995) Options for the control of elephants in conflict with people. *Pachyderm,* **19,** 54-63.

Hoare, R.E. (1999a) Determinants of human-elephant conflict in a land-use mosaic. *Journal of Applied Ecology,* **36,** 689-700.

Hoare, R.E. (1999b) A standardised data collection and analysis protocol for human-elephant conflict situations in Africa. IUCN African Elephant Specialist Group, Nairobi.

Hoare, R.E. (2000a) African elephants and humans in conflict: the outlook for co-existence. *Oryx,* **34,** 34-38.

Hoare, R.E. (2000b) Compensation schemes for agricultural and other damage caused by elephants (AfESG Technical Brief Series). *AfESG Technical Brief Series*. IUCN AfESG, Human Elephant Conflict Working Group, Nairobi, Kenya.

Hoare, R.E. (2012) Lessons from 15 years of human-elephant conflict mitigation: management considerations involving biological, physical and governance issues in Africa. *Pachyderm,* **51,** 60-74.

Hoare, R.E. (2015) Lessons from 20 years of human–elephant conflict mitigation in Africa. *Human Dimensions of Wildlife,* **20,** 289-295.

Hoare, R.E. & Du Toit, J.T. (1999) Coexistence between people and elephants in African savannas. *Conservation Biology,* **13,** 633-639.

Hockings, K.J., Yamakoshi, G., Kabasawa, A. & Matsuzawa, T. (2010) Attacks on local persons by chimpanzees in Bossou, Republic of Guinea: long-term perspectives. *American Journal of Primatology,* **72,** 887-896.

Hoffmeier-Karimi, R.R. & Schulte, B.A. (2014) Assessing perceived and documented crop damage in a Tanzanian village impacted by human-elephant conflict (HEC). *Pachyderm,* **56,** 51-60.

Hollister-Smith, J.A., Poole, J.H., Archie, E.A., Vance, E.A., Georgiadis, N.J., Moss, C.J. & Alberts, S.C. (2007) Age, musth and paternity success in wild male African elephants, *Loxodonta africana*. *Animal Behaviour,* **74,** 287-296.

Hsiao, S.S., Ross, C., Hill, C.M. & Wallace, G.E. (2013) Crop-raiding deterrents around Budongo Forest Reserve: an evaluation through farmer actions and perceptions. *Oryx,* **47,** 569-577.

Hussain, S. (2003) The status of the snow leopard in Pakistan and its conflict with local farmers. *Oryx,* **37,** 26-33.

Independent Evaluation Group Review Team (2017) Botswana - NB Human Wildlife Coexistence Project. *Implementation Completion Report Review*. World Bank Group, Washington, D.C.

Itzchakov, G., Uziel, L. & Wood, W. (2018) When attitudes and habits don't correspond: self-control depletion increases persuasion but not behavior. *Journal of Experimental Social Psychology,* **75,** 1-10.

Jackson, T.R., Mosojane, S., Ferreira, S.M. & van Aarde, R.J. (2008) Solutions for elephant *Loxodonta africana* crop raiding in northern Botswana: moving away from symptomatic approaches. *Oryx,* **42,** 83-91.

Jacobsen, K.S. & Linnell, J.D.C. (2016) Perceptions of environmental justice and the conflict surrounding large carnivore management in Norway - implications for conflict management. *Biological Conservation,* **203,** 197-206.

Johnson, A.R., Wiens, J.A., Milne, B.T. & Crist, T.O. (1992) Animal movements and population dynamics in heterogeneous landscapes. *Landscape Ecology,* **7,** 63-75.

Kangwana, K. (1995) Human-elephant conflict: the challenge ahead. *Pachyderm,* **19,** 11-14.

Kansky, R., Kidd, M. & Knight, A.T. (2016) A wildlife tolerance model and case study for understanding human wildlife conflicts. *Biological Conservation,* **201,** 137-145.

Kansky, R. & Knight, A.T. (2014) Key factors driving attitudes towards large mammals in conflict with humans. *Biological Conservation,* **179,** 93-105.

Karlsson, J. & Sjostrom, M. (2007) Human attitudes towards wolves, a matter of distance. *Biological Conservation,* **137,** 610-616.

KAZA TFCA (2015) Kavango-Zambezi Transfrontier Conservation Area. Access date: 05/03/18. http://www.kavangozambezi.org.

Khorozyan, I., Ghoddousi, A., Soofi, M. & Waltert, M. (2015) Big cats kill more livestock when wild prey reaches a minimum threshold. *Biological Conservation,* **192,** 268-275.

Kiiru, W. (1995) The current status of human-elephant conflict in Kenya. *Pachyderm,* **19,** 15-19.

King, L.E., Lala, F., Nzumu, H., Mwambingu, E. & Douglas-Hamilton, I. (2017) Beehive fences as a multidimensional conflict-mitigation tool for farmers coexisting with elephants. *Conservation Biology,* **31,** 743-752.

King, L.E., Lawrence, A., Douglas-Hamilton, I. & Vollrath, F. (2009) Beehive fence deters crop-raiding elephants. *African Journal of Ecology,* **47,** 131-137.

Kioko, J., Muruthi, P., Omondi, P. & Chiyo, P.I. (2008) The performance of electric fences as elephant barriers in Amboseli, Kenya. *South African Journal of Wildlife Research,* **38,** 52-58.

Klenke, R., Ring, I., Schwerdtner Manez, K., Habighorst, R., Weiss, V., Wittmer, H., Gruber, B., Lampa, S. & Henle, K. (2013) Otters in Saxony: a story of successful conflict resolution. *Human-wildlife conflicts in Europe* (eds R.A. Klenke, I. Ring, A. Kranz, N. Jepson, F. Rauschmayer & K. Henle), pp. 107-140. Springer-Verlag Berlin Heidelberg, Berlin.

Kloskowski, J. (2005) Otter *Lutra lutra* damage at farmed fisheries in southeastern Poland, I: an interview survey. *Wildlife Biology,* **11,** 201-206.

Kolowski, J.M. & Holekamp, K.E. (2006) Spatial, temporal, and physical characteristics of livestock depredations by large carnivores along a Kenyan reserve border. *Biological Conservation,* **128,** 529-541.

Krebs, J.R. & Davies, N.B. (1991) *Behavioural ecology: an evolutionary approach,* 3rd edn. Blackwell Scientific Publications, Oxford, UK.

Ladle, A., Steenweg, R., Shepherd, B. & Boyce, M.S. (2018) The role of human outdoor recreation in shaping patterns of grizzly bear-black bear co-occurrence. *Plos One,* **13,** e0191730.

Lahm, S.A. (1996) A nationwide survey of crop-raiding by elephants and other species in Gabon. *Pachyderm,* **21,** 69-77.

Lee, P.C. & Moss, C.J. (1986) Early maternal investment in male and female African elephant calves. *Behavioral Ecology and Sociobiology,* **18,** 353-361.

Legendre, P. & Legendre, L. (1998) *Numerical ecology: developments in environmental modelling 20*. Elsevier, Amsterdam, the Netherlands.

Lewin, M. (2011) Botswana's success: good governance, good policies, and good luck. *Yes, Africa can: success stories from a dynamic continent* (eds C.P. Pum & M. Angwafo), pp. 81-90. World Bank, Washington DC.

Lichtenfeld, L.L., Trout, C. & Kisimir, E.L. (2015) Evidence-based conservation: predator-proof bomas protect livestock and lions. *Biodiversity and Conservation,* **24,** 483-491.

Lindsey, P.A., du Toit, J.T. & Mills, M.G.L. (2005) Attitudes of ranchers towards African wild dogs *Lycaon pictus*: conservation implications on private land. *Biological Conservation,* **125,** 113-121.

Linkie, M., Dinata, Y., Nofrianto, A. & Leader-Williams, N. (2007) Patterns and perceptions of wildlife crop raiding in and around Kerinci Seblat National Park, Sumatra. *Animal Conservation,* **10,** 127-135.

Linnell, J.D.C., Nilsen, E.B., Lande, U.S., Herfindal, I., Odden, J., Skogen, K., Andersen, R. & Breitenmoser, U. (2005) Zoning as a means of mitigating conflicts with large carnivores: principles and reality. *People and wildlife, conflict or coexistence* (eds A. Rabinowitz, R. Woodroffe & S. Thirgood), pp. 162-175. Cambridge University Press, Cambridge.

Loarie, S.R., Van Aarde, R.J. & Pimm, S.L. (2009) Fences and artificial water affect African savannah elephant movement patterns. *Biological Conservation,* **142,** 3086-3098.

Mackenzie, C.A. & Ahabyona, P. (2012) Elephants in the garden: financial and social costs of crop raiding. *Ecological Economics,* **75,** 72-82.

Madden, F. (2004) Creating coexistence between humans and wildlife: global perspectives on local efforts to address human–wildlife conflict. *Human Dimensions of Wildlife,* **9,** 247-257.

Madden, F. & McQuinn, B. (2014) Conservation's blind spot: the case for conflict transformation in wildlife conservation. *Biological Conservation,* **178,** 97-106.

Madhusudan, M.D. (2003) Living amidst large wildlife: livestock and crop depredation by large mammals in the interior villages of Bhadra Tiger Reserve, south India. *Environmental Management,* **31,** 466-475.

Malema, B. (2012) Botswana's formal economic structure as a possible source of poverty: are there policies out of this economic impasse? *Pula: Botswana Journal of African Studies,* **26,** 51-70.

Mandelbrot, B. (1967) How long is the coast of Britain? Statistical self-similarity and fractional dimension. *Science,* **156,** 636-638.

Manfredo, M.J. (1989) Human dimensions of wildlife management. *Wildlife Society Bulletin,* **17,** 447-449.

Manfredo, M.J., Teel, T.L. & Henry, K.L. (2009) Linking society and environment: a multilevel model of shifting wildlife value orientations in the western United States. *Social Science Quarterly,* **90,** 407-427.

Marchini, S. (2014) Who's in conflict with whom? Human dimensions of the conflicts involving wildlife. *Applied ecology and human dimensions in biological conservation* (eds L.M. Verdade, M.C. Lyra-Jorge & C.I. Piña), pp. 189-209. Springer Berlin Heidelberg, Berlin, Heidelberg.

Marchini, S. & Macdonald, D.W. (2012) Predicting ranchers' intention to kill jaguars: case studies in Amazonia and Pantanal. *Biological Conservation,* **147,** 213-221.

Marino, A., Braschi, C., Ricci, S., Salvatori, V. & Ciucci, P. (2016) Ex post and insurance-based compensation fail to increase tolerance for wolves in semi-agricultural landscapes of central Italy. *European Journal of Wildlife Research,* **62,** 227-240.

Marker, L.L., Dickman, A.J. & Macdonald, D.W. (2005) Perceived effectiveness of livestock-guarding dogs placed on Namibian farms. *Rangeland Ecology & Management,* **58,** 329-336.

Marshall, K., White, R. & Fischer, A. (2007) Conflicts between humans over wildlife management: on the diversity of stakeholder attitudes and implications for conflict management. *Biodiversity and Conservation,* **16,** 3129-3146.

Mascia, M.B. & Mills, M. (2018) When conservation goes viral: the diffusion of innovative biodiversity conservation policies and practices. *Conservation Letters,* **11,** e12442.

Maude, G. (2010) The spatial ecology and foraging behaviour of the brown hyaena (*Hyaena brunnea*). PhD, University of Bristol.

Mayberry, A., Hovorka, A. & Evans, K. (2017) Well-being impacts of human-elephant conflict in Khumaga, Botswana: exploring visible and hidden dimensions. *Conservation and Society,* **15,** 280-291.

Mbaiwa, J.E. (2017) Effects of the safari hunting tourism ban on rural livelihoods and wildlife conservation in northern Botswana. *South African Geographical Journal,* **100,** 41-61.

Mbata, K.J. (1992) The biology and host plant specificity of *Acanthoplus speiseri* Brancsik (Orthoptera: Tettigoniidae: Hetrodinae), a pest of grain crops. *Journal of the Entomological Society of Southern Africa,* **55,** 99-106.

McNutt, J.W., Stein, A.B., McNutt, L.B. & Jordan, N.R. (2017) Living on the edge: characteristics of human–wildlife conflict in a traditional livestock community in Botswana. *Wildlife Research,* **44,** 546-557.

Meijaard, E., Buchori, D., Hadiprakarsa, Y., Utami-Atmoko, S.S., Nurcahyo, A., Tjiu, A., Prasetyo, D., Nardiyono, Christie, L., Ancrenaz, M., Abadi, F., Antoni, I.N.G., Armayadi, D., Dinato, A., Ella, Gumelar, P., Indrawan, T.P., Kussaritano, Munajat, C., Priyono, C.W.P., Purwanto, Y., Puspitasari, D., Putra, M.S.W., Rahmat, A., Ramadani, H., Sammy, J., Siswanto, D., Syamsuri, M., Andayani, N., Wu, H.H., Wells, J.A. & Mengersen, K. (2011) Quantifying killing of orangutans and human-orangutan conflict in Kalimantan, Indonesia. *Plos One,* **6,** e27491.

Merkle, J.A., Robinson, H.S., Krausman, P.R. & Alaback, P. (2013) Food availability and foraging near human developments by black bears. *Journal of Mammalogy,* **94,** 378-385.

Miller, J.R.B., Jhala, Y.V., Jena, J. & Schmitz, O.J. (2015) Landscape-scale accessibility of livestock to tigers: implications of spatial grain for modeling predation risk to mitigate human–carnivore conflict. *Ecology and Evolution,* **5,** 1354-1367.

Milne, B.T. (1991) Lessons from applying fractal models to landscape patterns. *Quantitative methods in landscape ecology* (eds M.G. Turner & R.H. Gardner), pp. 199-235. Springer-Verlag, New York, NY.

Ministry of Agriculture (2013) Guidelines for integrated support programme for arable agriculture development (ISPAAD).

Montgomery, R.A., Hoffmann, C.F., Tans, E.D. & Kissui, B. (2018) Discordant scales and the potential pitfalls for human-carnivore conflict mitigation. *Biological Conservation,* **224,** 170-177.

Mordi, A.R. (1989) The future of animal wildlife and its habitat in Botswana. *Environmental Conservation,* **16,** 147-156.

Mordi, R. (1987) Public attitudes toward wildlife in Botswana. PhD, Yale University.

Morzillo, A.T., Mertig, A.G., Hollister, J.W., Garner, N. & Liu, J.G. (2010) Socioeconomic factors affecting local support for black bear recovery strategies. *Environmental Management,* **45,** 1299-1311.

Mosojane, S. (2004) Human-elephant conflict along the Okavango Panhandle in northern Botswana. MSc, University of Pretoria.

Moss, C. (1996) Getting to know a population. *Studying elephants* (ed. K. Kangwana), pp. 58-74. The African Wildlife Foundation, Nairobi, Kenya.

Moss, C. & Poole, J. (1983) Relationships and social structure of African elephants. *Primate social relationships: an integrated approach* (ed. R.A. Hinde), pp. 315-325. Blackwell Scientific Publications, Oxford.

Motulsky, H.J. & Christopoulos, A. (2003) Fitting models to biological data using linear and nonlinear regression. A practical guide to curve fitting. GraphPad Software Inc., San Diego CA.

Mutinda, M., Chenge, G., Gakuya, F., Otiende, M., Omondi, P., Kasiki, S., Soriguer, R.C. & Alasaad, S. (2014) Detusking fence-breaker elephants as an approach in human-elephant conflict mitigation. *Plos One,* **9,** e91749.

Nams, V.O. (2005) Using animal movement paths to measure response to spatial scale. *Oecologia,* **143,** 179-188.

Nams, V.O. (2006) Improving accuracy and precision in estimating fractal dimension of animal movement paths. *Acta Biotheoretica,* **54,** 1-11.

Nams, V.O. & Bourgeois, M. (2004) Fractal analysis measures habitat use at different spatial scales: an example with American marten. *Canadian Journal of Zoology,* **82,** 1738-1747.

Nath, N.K., Lahkar, B.P., Dutta, S.K. & Das, J.P. (2015) Human-elephant conflict around Manas National Park, India: local people's attitudes, expectations and perceptions. *Gajah,* **42,** 15-21.

Naughton-Treves, L. (1998) Predicting patterns of crop damage by wildlife around Kibale National Park, Uganda. *Conservation Biology,* **12,** 156-168.

Naughton-Treves, L., Grossberg, R. & Treves, A. (2003) Paying for tolerance: rural citizens' attitudes toward wolf depredation and compensation. *Conservation Biology,* **17,** 1500-1511.

Naughton-Treves, L., Treves, A., Chapman, C. & Wrangham, R. (1998) Temporal patterns of crop-raiding by primates: linking food availability in croplands and adjacent forest. *Journal of Applied Ecology,* **35,** 596-606.

Naughton, L., Rose, R. & Treves, A. (1999) The social dimensions of human-elephant conflict in Africa: a literature review and case studies from Uganda and Cameroon. *A report to the African Elephant Specialist, Human-Elephant Conflict Task Force, of IUCN*. Glands, Switzerland.

Noser, R. & Byrne, R.W. (2007) Travel routes and planning of visits to out-of-sight resources in wild chacma baboons, *Papio ursinus*. *Animal Behaviour,* **73,** 257-266.

Nowell, K., Li, J., Paltsyn, M. & Sharma, R.K. (2016) *An ounce of prevention: snow leopard crime revisited*. TRAFFIC, Cambridge, UK.

Nyhus, P., Fischer, H., Madden, F. & Osofsky, S. (2003) Taking the bite out of wildlife damage: the challenges of wildlife compensation schemes. *Conservation in Practice,* **4,** 37-43.

Nyhus, P.J., Osofsky, S.A., Ferraro, P., Madden, F. & Fischer, H. (2005) Bearing the costs of human–wildlife conflict: the challenges of compensation schemes. *People and wildlife, conflict or co-existence?* (eds A. Rabinowitz, R. Woodroffe & S. Thirgood), pp. 107-121. Cambridge University Press, Cambridge.

Nyhus, P.J., Tilson, R. & Sumianto (2000) Crop-raiding elephants and conservation implications at Way Kambas National Park, Sumatra, Indonesia. *Oryx,* **34,** 262-274.

O'Connell-Rodwell, C.E., Rodwell, T., Rice, M. & Hart, L.A. (2000) Living with the modern conservation paradigm: can agricultural communities co-exist with elephants? A five-year case study in East Caprivi, Namibia. *Biological Conservation,* **93,** 381-391.

Obanda, V., Ndeereh, D., Mijele, D., Lekolool, I., Chege, S., Gakuya, F. & Omondi, P. (2008) Injuries of free ranging African elephants (*Loxodonta africana africana*) in various ranges of Kenya. *Pachyderm,* **44,** 54-58.

Odden, J., Linnell, J.D.C., Moa, P.F., Herfindal, I., Kvam, T. & Andersen, R. (2002) Lynx depredation on domestic sheep in Norway. *Journal of Wildlife Management,* **66,** 98-105.

Odden, J., Nilsen, E.B. & Linnell, J.D.C. (2013) Density of wild prey modulates lynx kill rates on free-ranging domestic sheep. *Plos One,* **8,** e79261.

Ogra, M.V. (2008) Human-wildlife conflict and gender in protected area borderlands: a case study of costs, perceptions, and vulnerabilities from Uttarakhand (Uttaranchal), India. *Geoforum,* **39,** 1408-1422.

Ogra, M.V. & Badola, R. (2008) Compensating human-wildlife conflict in protected area communities: ground-level perspectives from Uttarakhand, India. *Human Ecology,* **36,** 717-729.

Okello, M.M., Njumbi, S.J., Kiringe, J.W. & Isiiche, J. (2014) Prevalence and severity of current human-elephant conflicts in Amboseli ecosystem, Kenya: insights from the field and key informants. *Natural Resources,* **5,** 462-477.

Osborn, F.V. (1998) Ecology of crop raiding elephants. *Pachyderm,* **25,** 39-40.

Osborn, F.V. (2002) Capsicum oleoresin as an elephant repellent: field trials in the communal lands of Zimbabwe. *Journal of Wildlife Management,* **66,** 674-677.

Osborn, F.V. (2004) Seasonal variation of feeding patterns and food selection by crop-raiding elephants in Zimbabwe. *African Journal of Ecology,* **42,** 322-327.

Osborn, F.V. & Parker, G.E. (2002) Community-based methods to reduce crop loss to elephants: experiments in the communal lands of Zimbabwe. *Pachyderm,* **33,** 32-38.

Osborn, F.V. & Parker, G.E. (2003) Towards an integrated approach for reducing the conflict between elephants and people: a review of current research. *Oryx,* **37,** 80-84.

Owen-Smith, R.N. (1988) *Megaherbivores: the influence of very large body size on ecology*. Cambridge University Press, Cambridge.

Parker, G.E. & Osborn, F.V. (2001) Dual-season crop damage by elephants in eastern Zambezi Valley, Zimbabwe. *Pachyderm,* **30,** 49-56.

Parker, G.E. & Osborn, F.V. (2006) Investigating the potential for chilli *Capsicum* spp. to reduce human-wildlife conflict in Zimbabwe. *Oryx,* **40,** 343-346.

Parry, D. & Campbell, B. (1992) Attitudes of rural communities to animal wildlife and its utilization in Chobe Enclave and Mababe Depression, Botswana. *Environmental Conservation,* **19,** 245-252.

Penteriani, V., Delgado, M.D., Pinchera, F., Naves, J., Fernandez-Gil, A., Kojola, I., Harkonen, S., Norberg, H., Frank, J., Fedriani, J.M., Sahlen, V., Stoen, O.G., Swenson, J.E., Wabakken, P., Pellegrini, M., Herrero, S. & Lopez-Bao, J.V. (2016) Human behaviour can trigger large carnivore attacks in developed countries. *Scientific Reports,* **6,** 20552.

Peterson, M.N., Birckhead, J.L., Leong, K., Peterson, M.J. & Peterson, T.R. (2010) Rearticulating the myth of human-wildlife conflict. *Conservation Letters,* **3,** 74-82.

Piedallu, B., Quenette, P.Y., Mounet, C., Lescureux, N., Borelli-Massines, M., Dubarry, E., Camarra, J.J. & Gimenez, O. (2016) Spatial variation in public attitudes towards brown bears in the French Pyrenees. *Biological Conservation,* **197,** 90-97.

Pitfield, A.R. (2017) The social and environmental factors affecting the life of bull African elephants (*Loxodonta africana*) in a "bull area" - a social network analysis. MSc, University of Bristol.

Pittiglio, C., Skidmore, A.K., van Gils, H., McCall, M.K. & Prins, H.H.T. (2014) Smallholder farms as stepping stone corridors for crop-raiding elephant in northern Tanzania: integration of Bayesian expert system and network simulator. *Ambio,* **43,** 149-161.

Polansky, L., Kilian, W. & Wittemyer, G. (2015) Elucidating the significance of spatial memory on movement decisions by African savannah elephants using state-space models. *Proceedings of the Royal Society B-Biological Sciences,* **282,** 20143042.

Poole, J.H. (1989) Mate guarding, reproductive success and female choice in African elephants. *Animal Behaviour,* **37,** 842-849.

Poole, J.H. (1996) The African elephant. *Studying elephants* (ed. K. Kangwana), pp. 1-8. The African Wildlife Foundation, Nairobi, Kenya.

Pooley, S., Barua, M., Beinart, W., Dickman, A., Holmes, G., Lorimer, J., Loveridge, A.J., Macdonald, D.W., Marvin, G., Redpath, S., Sillero-Zubiri, C., Zimmermann, A. & Milner-Gulland, E.J. (2017) An interdisciplinary review of current and future approaches to improving human–predator relations. *Conservation Biology,* **31,** 513-523.

Pozo, R.A., Coulson, T., McCulloch, G., Stronza, A. & Songhurst, A. (2017) Chilli-briquettes modify the temporal behaviour of elephants, but not their numbers. *Oryx***,** 1-9.

Rabinowitz, A. (2005) Jaguars and livestock: living with the world's third largest cat. *People and wildlife, conflict or co-existence?* (eds A. Rabinowitz, R. Woodroffe & S. Thirgood), pp. 278-285. Cambridge University Press, Cambridge.

Ravenelle, J. & Nyhus, P.J. (2017) Global patterns and trends in human–wildlife conflict compensation. *Conservation Biology,* **31,** 1247-1256.

Redpath, S.M., Gutiérrez, R.J., Wood, K.A. & Young, J.C. (2015) *Conflicts in conservation: navigating towards solutions*. Cambridge University Press.

Redpath, S.M., Linnell, J.D.C., Festa-Bianchet, M., Boitani, L., Bunnefeld, N., Dickman, A., Gutiérrez, R.J., Irvine, R.J., Johansson, M., Majić, A., McMahon, B.J., Pooley, S., Sandström, C., Sjölander-Lindqvist, A., Skogen, K., Swenson, J.E., Trouwborst, A., Young, J. & Milner-Gulland, E.J. (2017) Don't forget to look down – collaborative approaches to predator conservation. *Biological Reviews,* **92,** 2157-2163.

Redpath, S.M., Young, J., Evely, A., Adams, W.M., Sutherland, W.J., Whitehouse, A., Amar, A., Lambert, R.A., Linnell, J.D.C., Watt, A. & Gutierrez, R.J. (2013) Understanding and managing conservation conflicts. *Trends in Ecology & Evolution,* **28,** 100-109.

Revelle, W. (2018) psych: procedures for psychological, psychometric, and personality research. Northwestern University, Evanston, Illinois.

Roca, A.L., Georgiadis, N., Pecon-Slattery, J. & Brien, S.J. (2001) Genetic evidence for two species of elephant in Africa. *Science,* **293,** 1473-1477.

Rode, K.D., Chiyo, P.I., Chapman, C.A. & McDowell, L.R. (2006) Nutritional ecology of elephants in Kibale National Park, Uganda, and its relationship with crop-raiding behaviour. *Journal of Tropical Ecology,* **22,** 441-449.

Romanach, S.S., Lindsey, P.A. & Woodroffe, R. (2007) Determinants of attitudes towards predators in central Kenya and suggestions for increasing tolerance in livestock dominated landscapes. *Oryx,* **41,** 185-195.

Rust, N.A., Abrams, A., Challender, D.W.S., Chapron, G., Ghoddousi, A., Glikman, J.A., Gowan, C.H., Hughes, C., Rastogi, A., Said, A., Sutton, A., Taylor, N., Thomas, S., Unnikrishnan, H., Webber, A.D., Wordingham, G. & Hill, C.M. (2017) Quantity does not always mean quality: the importance of qualitative social science in conservation research. *Society & Natural Resources,* **30,** 1304-1310.

Rust, N.A. & Marker, L.L. (2013) Attitudes toward predators and conservancies among Namibian farmers. *Human Dimensions of Wildlife,* **18,** 463-468.

Saberwal, V.K., Gibbs, J.P., Chellam, R. & Johnsingh, A.J.T. (1994) Lion human conflict in the Gir Forest, India. *Conservation Biology,* **8,** 501-507.

Saj, T., Sicotte, P. & Paterson, J.D. (1999) Influence of human food consumption on the time budget of vervets. *International Journal of Primatology,* **20,** 977-994.

Sam, M.K., Danquah, E., Oppong, S.K. & Ashie, E.A. (2005) Nature and extent of human-elephant conflict in Bia Conservation Area, Ghana. *Pachyderm,* **38,** 49-58.

Sam, M.K., Haziel, C.A.K. & Barnes, R.F.W. (2002) Crop damage by elephants in the Red Volta area during the 1997 harvesting season. *Human wildlife conflict: identifying the problem and possible solutions* (eds C.M. Hill, F.V. Osborn & A.J. Plumptre), pp. 126-135. Wildlife Conservation Society, New York, NY.

Sangay, T. & Vernes, K. (2008) Human-wildlife conflict in the Kingdom of Bhutan: patterns of livestock predation by large mammalian carnivores. *Biological Conservation,* **141,** 1272-1282.

Santiago-Avila, F.J., Cornman, A.M. & Treves, A. (2018) Killing wolves to prevent predation on livestock may protect one farm but harm neighbors. *Plos One,* **13,** e0189729.

Schwerdtner, K. & Gruber, B. (2007) A conceptual framework for damage compensation schemes. *Biological Conservation,* **134,** 354-360.

Shannon, G., Matthews, W.S., Page, B.R., Parker, G.E. & Smith, R.J. (2009) The affects of artificial water availability on large herbivore ranging patterns in savanna habitats: a new approach based on modelling elephant path distributions. *Diversity and Distributions,* **15,** 776-783.

Shannon, G., Page, B.R., Duffy, K.J. & Slotow, R. (2006) The role of foraging behaviour in the sexual segregation of the African elephant. *Oecologia,* **150,** 344-354.

Sitati, N.W. & Walpole, M.J. (2006) Assessing farm-based measures for mitigating human-elephant conflict in Transmara District, Kenya. *Oryx,* **40,** 279-286.

Sitati, N.W., Walpole, M.J. & Leader-Williams, N. (2005) Factors affecting susceptibility of farms to crop raiding by African elephants: using a predictive model to mitigate conflict. *Journal of Applied Ecology,* **42,** 1175-1182.

Sitati, N.W., Walpole, M.J., Smith, R.J. & Leader-Williams, N. (2003) Predicting spatial aspects of human-elephant conflict. *Journal of Applied Ecology,* **40,** 667-677.

Sitienei, A.J., Jiwen, G. & Ngene, S.M. (2014) Assessing the cost of living with elephants (*Loxodonta africana*) in areas adjacent to Meru National Park, Kenya. *European Journal of Wildlife Research,* **60,** 323-330.

Slotow, R., Balfour, D. & Howison, O. (2001) Killing of black and white rhinoceroses by African elephants in Hluhluwe-Umfolozi Park, South Africa. *Pachyderm,* **31,** 14-20.

Slotow, R. & van Dyk, G. (2001) Role of delinquent young "orphan" male elephants in high mortality of white rhinoceros in Pilanesberg National Park, South Africa. *Koedoe,* **44,** 85-94.

Slotow, R., van Dyk, G., Poole, J., Page, B. & Klocke, A. (2000) Older bull elephants control young males. *Nature,* **408,** 425-426.

Smit, J., Pozo, R.A., Cusack, J.J., Nowak, K. & Jones, T. (2017) Using camera traps to study the age–sex structure and behaviour of crop-using elephants *Loxodonta africana* in Udzungwa Mountains National Park, Tanzania. *Oryx***,** 1-9.

Smith, D.W., Peterson, R.O. & Houston, D.B. (2003) Yellowstone after wolves. *Bioscience,* **53,** 330-340.

Smith, J.R. & Kasiki, S.M. (2000) A spatial analysis of human-elephant conflict in the Tsavo ecosystem, Kenya. Human-Elephant Conflict Taskforce, IUCN, Gland, Switzerland.

Songhurst, A. (2017) Measuring human–wildlife conflicts: comparing insights from different monitoring approaches. *Wildlife Society Bulletin,* **41,** 351-361.

Songhurst, A. & Coulson, T. (2014) Exploring the effects of spatial autocorrelation when identifying key drivers of wildlife crop-raiding. *Ecology and Evolution,* **4,** 582-593.

Songhurst, A., McClloch, G. & Coulson, T. (2016) Finding pathways to human-elephant coexistence: a risky business. *Oryx,* **50,** 713-720.

Stander, P.E. (1990) A suggested management strategy for stock-raiding lions in Namibia. *South African Journal of Wildlife Research,* **20,** 37-43.

Statistics Botswana (2014) Population and housing census 2011: analytical report. Statistics Botswana, Gaborone.

Stokke, S. & du Toit, J.T. (2000) Sex and size related differences in the dry season feeding patterns of elephants in Chobe National Park, Botswana. *Ecography,* **23,** 70-80.

Stokke, S. & du Toit, J.T. (2002) Sexual segregation in habitat use by elephants in Chobe National Park, Botswana. *African Journal of Ecology,* **40,** 360-371.

Strum, S.C. (1994) Prospects for management of primate pests. *Revue d'Ecologie (La Terre et la Vie),* **49,** 295-306.

Sukumar, R. (1990) Ecology of the Asian elephant in southern India .2. Feeding-habits and crop raiding patterns. *Journal of Tropical Ecology,* **6,** 33-53.

Sukumar, R. & Gadgil, M. (1988) Male-female differences in foraging on crops by Asian elephants. *Animal Behaviour,* **36,** 1233-1235.

Suryawanshi, K.R., Bhatnagar, Y.V., Redpath, S. & Mishra, C. (2013) People, predators and perceptions: patterns of livestock depredation by snow leopards and wolves. *Journal of Applied Ecology,* **50,** 550-560.

Sutherland, W.J., Pullin, A.S., Dolman, P.M. & Knight, T.M. (2004) The need for evidence-based conservation. *Trends in Ecology & Evolution,* **19,** 305-308.

Tchamba, M.N. (1996) History and present status of the human elephant conflict in the Waza-Logone region, Cameroon, west Africa. *Biological Conservation,* **75,** 35-41.

Teichman, K.J., Cristescu, B. & Nielsen, S.E. (2013) Does sex matter? Temporal and spatial patterns of cougar-human conflict in British Columbia. *Plos One,* **8,** e74663.

Thirgood, S. & Redpath, S. (2008) Hen harriers and red grouse: science, politics and human-wildlife conflict. *Journal of Applied Ecology,* **45,** 1550-1554.

Thirgood, S., Woodroffe, R. & Rabinowitz, A. (2005) The impact of human–wildlife conflict on human lives and livelihoods. *People and wildlife, conflict or co-existence?* (eds A. Rabinowitz, R. Woodroffe & S. Thirgood), pp. 13-26. Cambridge University Press, Cambridge.

Thomas, D.S.G. & Shaw, P.A. (1991) *The Kalahari environment*. Cambridge University Press, Cambridge.

Thouless, C.R. (1994) Conflict between humans and elephants on private land in northern Kenya. *Oryx,* **28,** 119-127.

Thouless, C.R., Dublin, H.T., Blanc, J.J., Skinner, D.P., Daniel, T.E., Taylor, R.D., Maisels, F., Frederick, H.L. & Bouche, P. (2016) African elephant status report 2016: an update from the African Elephant Database. *Occasional Paper Series of the IUCN Species Survival Commission, No. 60 IUCN/SSC African Elephant Specialist Group*. IUCN, Gland, Switzerland.

Thouless, C.R. & Sakwa, J. (1995) Shocking elephants: fences and crop raiders in Laikipia district, Kenya. *Biological Conservation,* **72,** 99-107.

Tombre, I.M., Eythórsson, E. & Madsen, J. (2013) Towards a solution to the goose-agriculture conflict in north Norway, 1988–2012: the interplay between policy, stakeholder influence and goose population dynamics. *Plos One,* **8,** e71912.

Treves, A., Naughton-Treves, L., Harper, E.K., Mladenoff, D.J., Rose, R.A., Sickley, T.A. & Wydeven, A.P. (2004) Predicting human-carnivore conflict: a spatial model derived from 25 years of data on wolf predation on livestock. *Conservation Biology,* **18,** 114-125.

UNDP-UNEP PEI (2013) Support to smallholder arable farmers in Botswana: agricultural development or social protection? UNDP-UNEP Poverty Environment Initiative, Gaborone, Botswana.

Vaclavikova, M., Vaclavik, T. & Kostkan, V. (2011) Otters vs. fishermen: stakeholders' perceptions of otter predation and damage compensation in the Czech Republic. *Journal for Nature Conservation,* **19,** 95-102.

Valeix, M., Hemson, G., Loveridge, A.J., Mills, G. & Macdonald, D.W. (2012) Behavioural adjustments of a large carnivore to access secondary prey in a human-dominated landscape. *Journal of Applied Ecology,* **49,** 73-81.

van Eeden, L.M., Crowther, M.S., Dickman, C.R., Macdonald, D.W., Ripple, W.J., Ritchie, E.G. & Newsome, T.M. (2018) Managing conflict between large carnivores and livestock. *Conservation Biology,* **32,** 26-34.

Venables, W.N. & Ripley, B.D. (2002) *Modern applied statistics with S*. Springer, New York.

Venema, J.H. & Kgaswanyane, M. (1996) Agricultural land use plan for Letlhakane Agricultural District, Central Region. FAO/UNDP/Government of Botswana Project BOT/91/001.

Veríssimo, D. (2013) Influencing human behaviour: an underutilised tool for biodiversity management. *Conservation Evidence,* **10,** 29-31.

Verissimo, D., MacMillan, D.C. & Smith, R.J. (2011) Toward a systematic approach for identifying conservation flagships. *Conservation Letters,* **4,** 1-8.

Voigt, M., Wich, S.A., Ancrenaz, M., Meijaard, E., Abram, N., Banes, G.L., Campbell-Smith, G., d'Arcy, L.J., Delgado, R.A., Erman, A., Gaveau, D., Goossens, B., Heinicke, S., Houghton, M., Husson, S.J., Leiman, A., Sanchez, K.L., Makinuddin, N., Marshall, A.J., Meididit, A., Miettinen, J., Mundry, R., Musnanda, Nardiyono, Nurcahyo, A., Odom, K., Panda, A., Prasetyo, D., Priadjati, A., Purnomo, Rafiastanto, A., Russon, A.E., Santika, T., Sihite, J., Spehar, S., Struebig, M., Sulbaran-Romero, E., Tjiu, A., Wells, J., Wilson, K.A. & Kühl, H.S. (2018) Global demand for natural resources eliminated more than 100,000 Bornean orangutans. *Current Biology,* **28,** 761-769.

von Bertalanffy, L. (1960) Principles and theory of growth. *Fundamental aspects and theory of normal and malignant growth* (ed. W.W. Nowinski), pp. 137-259. Elsevier, Amsterdam, The Netherlands.

von Gerhardt, K., van Niekerk, A., Kidd, M., Samways, M. & Hanks, J. (2014) The role of elephant *Loxodonta africana* pathways as a spatial variable in crop-raiding location. *Oryx,* **48,** 436-444.

Wallace, G.E. & Hill, C.M. (2012) Crop damage by primates: quantifying the key parameters of crop-raiding events. *Plos One,* **7,** e46636.

Watve, M., Patel, K., Bayani, A. & Patil, P. (2016) A theoretical model of community operated compensation scheme for crop damage by wild herbivores. *Global Ecology and Conservation,* **5,** 58-70.

Webber, A.D., Hill, C.M. & Reynolds, V. (2007) Assessing the failure of a community-based human-wildlife conflict mitigation project in Budongo Forest Reserve, Uganda. *Oryx,* **41,** 177-184.

Webber, C.E., Sereivathana, T., Maltby, M.P. & Lee, P.C. (2011) Elephant crop-raiding and human-elephant conflict in Cambodia: crop selection and seasonal timings of raids. *Oryx,* **45,** 243-251.

Western, D. (1987) Africa's elephants and rhinos: flagships in crisis. *Trends in Ecology & Evolution,* **2,** 343-346.

Western, D. (1989) The ecological role of elephants in Africa. *Pachyderm,* **12,** 42-45.

Western, D., Moss, C. & Georgiadis, N. (1983) Age estimation and population age structure of elephants from footprint dimensions. *The Journal of Wildlife Managment,* **47,** 1192-1197.

White, P.C.L. & Ward, A.I. (2010) Interdisciplinary approaches for the management of existing and emerging human-wildlife conflicts. *Wildlife Research,* **37,** 623-629.

Williams, A.C., Johnsingh, A.J.T. & Krausman, P.R. (2001) Elephant-human conflicts in Rajaji National Park, northwestern India. *Wildlife Society Bulletin,* **29,** 1097-1104.

Wilson, M.L., Hauser, M.D. & Wrangham, R.W. (2007) Chimpanzees (*Pan troglodytes*) modify grouping and vocal behaviour in response to location-specific risk. *Behaviour,* **144,** 1621-1653.

Wilson, S., Davies, T.E., Hazarika, N. & Zimmermann, A. (2015) Understanding spatial and temporal patterns of human-elephant conflict in Assam, India. *Oryx,* **49,** 140-149.

Wilson, S.M., Madel, M.J., Mattson, D.J., Graham, J.M. & Merrill, T. (2006) Landscape conditions predisposing grizzly bears to conflicts on private agricultural lands in the western USA. *Biological Conservation,* **130,** 47-59.

Wittemyer, G., Douglas-Hamilton, I. & Getz, W.M. (2005) The socioecology of elephants: analysis of the processes creating multitiered social structures. *Animal Behaviour,* **69,** 1357-1371.

Woodroffe, R., Thirgood, S. & Rabinowitz, A. (2005) The future of coexistence: resolving human–wildlife conflicts in a changing world. *People and wildlife, conflict or co-existence?* (eds A. Rabinowitz, R. Woodroffe & S. Thirgood), pp. 388-405. Cambridge University Press, Cambridge.

World Bank (2015) Botswana-systematic country diagnostic. World Bank Group, Washington, DC.

Zarco-Gonzalez, M.M. & Monroy-Vilchis, O. (2014) Effectiveness of low-cost deterrents in decreasing livestock predation by felids: a case in central Mexico. *Animal Conservation,* **17,** 371-378.

Zimmermann, A., Davies, T.E., Hazarika, N., Wilson, S., Chakrabarty, J., Hazarika, B. & Das, D. (2009) Community-based human-elephant conflict management in Assam. *Gajah,* **30,** 34-40.

Zimmermann, A., Walpole, M.J. & Leader-Williams, N. (2005) Cattle ranchers' attitudes to conflicts with jaguar *Panthera onca* in the Pantanal of Brazil. *Oryx,* **39,** 406-412.

Supplementary information 1

Calculating the area, percentage, and value of damage in a field for IUCN and transect method data

Two different methods were followed to collect data on crop damage and composition as described in section 2.3.1. Below I outline how the area, percentage and value of damage were calculated, using data from both methods, after individual crop-foraging events and for total damage to fields at the end of the agricultural season.

IUCN: Having paced around damaged areas of a field following the IUCN data collection protocol described in section 2.3.1, paces were converted to metres based on the researchers' (Amy Chamberlain and James Stevens) mean pace length, outlined in Table S2.1. The area of damage (ha) was calculated using:

$$Ad(m^2) = Ld \times Wd$$

where $Ad(m^2)$ is the area of damage (m^2), Ld is the length of the damaged area (m) and Wd is the width of the damaged area (m). The area was converted from m^2 to ha. The proportion of the field damaged was then calculated using:

$$PdCr = Ad(ha) / TPA$$

where PdCr is the proportion of the field damaged after a crop-foraging event, Ad(ha) is the area of damage (ha) and TPA is the total ploughed area in the field (ha). Following the IUCN method meant that only new damage was recorded when attending multiple crop-foraging events in the same field. To calculate the total amount of damage (ha) at the end of the agricultural season, the area of damage for each crop-foraging event was summed:

$$Td = Ad(ha)\ R1 + Ad(ha)\ R2 + Ad(ha)\ Rn$$

where Td is the total area of damage (ha) and Ad(ha) R1 is the area of damage caused in the first crop-foraging event (ha), up to Ad(ha) Rn, the area of damage caused on the nth crop-foraging event (ha). The proportion of damage for each field at the end of the agricultural season was calculated using the total area ploughed (ha) and the total area damaged (ha):

$$PdF = Td / TPA$$

where PdF is the proportion of damage to a field at the end of the agricultural season, Td is the total area of damage (ha), TPA is the total ploughed area of the field (ha). Based on the total area of damage and the crop composition, the DWNP's value of compensation per hectare for each crop species (Table S2.2) was used to calculate the economic cost of damage for each crop:

$$Vd\ CA = (Td \times P\ CA) \times V\ CA$$

where Vd CA is the value of damage to crop A (BWP), Td is the total area of damage (ha), P CA is the proportion of crop A and V CA is the value of crop A per hectare (BWP). To calculate the total value of damage (BWP) at the end of the agricultural season, the value of damage for all crops in the field were summed:

$$TVD = Vd\ CA + Vd\ CB + Vd\ Cn$$

where TVD is the total value of damage (BWP), Vd CA is the value of damage to crop A (BWP), Vd CB is the value of damage to crop B (BWP), up to Vd Cn, the nth crop. This method assumes that the resulting damage to crops was randomly distributed. For example, if 50% of the crop was maize then 50% of the damage incurred was damage to maize.

Transects: Transects were completed as described in section 2.3.1. These produced counts of crop damage, for different crops, for both trampling and browsing damage. The counts of damage for each crop species were extrapolated from the 2.5% sample, to give an estimate of the actual number of damaged plants for each crop in the field. When repeat visits to fields were required due to multiple crop-foraging events, both new damage and old damage from prior crop-foraging events were recorded, resulting in cumulative counts of damage. To determine the damage that had occurred in the most recent crop-foraging event the difference in damage counts for each crop were calculated:

$$D\ CA\ R2 = TD\ CA\ R2 - TD\ CA\ R1$$

where D CA R2 is the damage to crop A that occurred during the second crop-foraging event, TD CA R2 is the total damage to crop A counted after the second crop-foraging event and TD CA R1 is the total damage to crop A counted after the first crop-foraging event. This resulted in counts of crop damage for each crop, for each crop-foraging event, in a field.

A single plant was assumed to occupy one pace-squared, therefore, paces-squared were converted to metres squared based on the researchers’ pace length. The area of damage in metres squared was then converted to hectares for each crop. The area of damage for each crop was summed to determine the total area of damage in the field.

Using the area of damage (ha) for each crop and the DWNP value of crops/ha, a value of damage was calculated for each crop:

$$Vd\ CA = D\ CA \times V\ CA$$

where Vd CA is the value of damage to crop A (BWP), D CA is the area of damage to crop A (ha) and V CA is the value of crop A per hectare (BWP). The total value of damage was calculated by summing the values of damage for each crop:

$$TVD = Vd\ CA + Vd\ CB + Vd\ Cn$$

where TVD is the total value of damage (BWP), Vd CA is the value of damage to crop A (BWP), Vd CB is the value of damage to crop B (BWP), up to Vd Cn, the nth crop. This provided a value of damage for each crop-foraging event. To calculate the proportion of damage occurring to a crop after a crop-foraging event, the total count of damage and total count of plants present were used:

$$PdCr = TCD / TCCP$$

where PdCr is the proportion of damage to a crop after a crop-foraging event, TCD is the total count of damaged plants and TCCP is the total count of plants present.

To determine the total damage occurring to a field at the end of an agricultural season, data were used from the final set of transects completed in a field. The above calculations were performed to calculate overall area, percentage, and value of damage in a field.

Table S2.1. Researchers' mean pace-length (m) ± SE

Researcher	Pace length (m) ± SE
Amy Chamberlain	0.76 ± 0.02
James Stevens	0.75 ± 0.01

Table S2.2. Values of compensation in BWP for different crops provided by the DWNP, Botswana, for cases of human-elephant interactions

Crop	Scientific name	Value of compensation/hectare (BWP)
Maize	*Zea mays*	900
Millet	*Pennisetum glaucum*	700
Sorghum	*Sorghum bicolour*	870
Watermelons*	*Citrullus lanatus*	16,500
Cowpeas	*Vigna unguiculata*	2500
Sweet reed	*Sorghum vulgare*	2000
Pumpkin*	*Cucurbita sp.*	16,500
Groundnut	*Arachis hypogaea*	2100
Lablab	*Lablab purpureus*	NA
Butternut*	*Cucurbita moschata*	16,500
Tomatoes*	*Solanum lycopersicum*	100,000
Green pepper*	*Capsicum annuum*	40,000
Chilli pepper	*Capsicum annuum*	NA

*represents horticultural crops

Table S2.3. The characteristics of fields in the Makgadikgadi region, Botswana (n=149)

	Year			Overall
	2014	2015	2016	
Number of crops grown	4.9 ± 0.2 (2-8)	4.7 ± 0.2 (1-8)	4.4 ± 0.2 (2-6)	4.8 ± 0.1 (1-8)
% of fields with:				
Maize	93.4% (71)	95.5% (43)	96.4% (27)	94.6% (141)
Millet	65.8% (50)	53.3% (23)	21.4% (6)	53.7% (79)
Sorghum	57.9% (44)	33.3% (15)	10.7% (3)	41.6% (62)
Watermelons	88.2% (67)	88.9% (40)	92.9% (26)	89.3% (123)
Cowpeas	86.8% (66)	86.7% (39)	71.4% (20)	83.9% (125)
Sweet reed	47.4% (36)	57.8% (26)	67.9% (19)	54.4% (81)
Pumpkin	28.9% (22)	57.8% (26)	60.7% (17)	43.6% (65)
Groundnut	2.6% (2)	6.7% (3)	3.6% (1)	4.0% (6)
Lablab	1.3% (1)	2.2% (1)	3.6% (1)	2.0% (3)
Butternut	10.5% (8)	0.0% (0)	0.0% (0)	5.4% (8)
Tomatoes	1.3% (1)	0.0% (0)	0.0% (0)	0.7% (1)
Green pepper	1.3% (1)	0.0% (0)	0.0% (0)	0.7% (1)
Chilli pepper	1.3% (1)	0.0% (0)	0.0% (0)	0.7% (1)

Mean ± SE (range)

Table S2.4. Shannon's Diversity Index scores across years, using data collected following the IUCN and transect method (IUCN n=128; Transect n=61)

Method	Year			Overall
	2014	2015	2016	
IUCN	1.9 ± <0.1 (0.4-1.8)	1.0 ± 0.1 (0.0-1.9)	0.8 ± 0.1 (0.1-1.5)	1.1 ± <0.1 (0.0-1.9)
Transect	-	1.0 ± 0.1 (0.0-1.8)	0.9 ± 0.1 (0.4-1.6)	1.0 ± 0.1 (0.0-1.8)

Mean ± SE (range)

Model 1:

Entered ~ distance from the MPNP + distance to nearest field + (1|year)

Neither variable was significant, either alone (distance to nearest field model compared to null model Δdeviance=0.337, d.f.=1, *P*=0.562; distance from the MPNP model compared to null model Δdeviance=0.089, d.f.=1, *P*=0.765) or in combination (distance to nearest field removed from full model Δdeviance=0.267, d.f.=1, *P*=0.606; distance from the MPNP removed from full model Δdeviance=0.019, d.f.=1, *P*=0.891) at influencing whether a field would be entered by elephants.

Model 2:

Number of crop-foraging events ~ distance from the MPNP + distance to nearest field + (1|year)

Neither variable was significant, either alone (distance from the MPNP model compared to null model Δdeviance=0.005, d.f.=1, *P*=0.946; distance to nearest field model compared to null model Δdeviance=0.673, d.f.=1, *P*=0.412) or in combination (distance to nearest field removed from full model Δdeviance=0.679, d.f.=1, *P*=0.410; distance from the MPNP removed from full model Δdeviance=0.011, d.f.=1, *P*=0.918) at influencing the frequency of a field being entered.

Model 4:

Value of damage ~ distance from the MPNP + distance to the nearest field + (1|year)

Neither variable was significant, either alone (distance to nearest field model compared to null model Δdeviance=3.555, d.f.=1, *P*=0.059; distance from the MPNP model compared to null model Δdeviance=0.984, d.f.=1, *P*=0.321) or in combination (distance to nearest field removed from full model Δdeviance=2.607, d.f.=1, *P*=0.106; distance from the MPNP removed from full model Δdeviance=0.037, d.f.=1, *P*=0.848) at influencing the value of damage caused in a field.

Model 5:
Entered ~ boundary type + area of field + crop diversity + (1|year)

None of the variables influenced whether a field was entered or not during an agricultural season, either alone (area model compared to null model Δdeviance=1.678, d.f.=1, *P*=0.195; boundary model compared to null model Δdeviance=1.692, d.f.=2, *P*=0.429; crop diversity model compared to null model Δdeviance=0.533, d.f.=1, *P*=0.466) or in combination (full model compared to model without area Δdeviance=1.211, d.f.=1, *P*=0.271; full model compared to model without boundary Δdeviance=1.255, d.f.=2, *P*=0.534; full model compared to model without crop diversity Δdeviance=0.727, d.f.=1, *P*=0.394; full model compared to model with just area Δdeviance=1.840, d.f.=3, *P*=0.606; full model compared to model with just boundary Δdeviance=1.826, d.f.=2, *P*=0.401; full model compared to model with just crop diversity Δdeviance=2.985, d.f.=3, P=0.394).

Model 6:
Area of damage ~ boundary type + area of field + crop diversity + (1|year)

None of the variables influenced the frequency of crop-foraging events during an agricultural season, either alone (area model compared to null model Δdeviance=3.309, d.f.=1, *P*=0.069; boundary model compared to null model Δdeviance=2.753, d.f.=2, *P*=0.253; crop diversity model compared to null model Δdeviance=0.760, d.f.=1, *P*=0.383) or in combination (full model compared to model without area Δdeviance=5.043, d.f.=1, *P*=0.025; full model compared to model without boundary Δdeviance=3.581, d.f.=2, *P*=0.167; full model compared to model without crop diversity Δdeviance=0.885, d.f.=1, *P*=0.347; full model compared to model with just area Δdeviance=4.872, d.f.=3, *P*=0.181; full model compared to model with just boundary Δdeviance=5.428, d.f.=2, *P*=0.066; full model compared to model with just crop diversity Δdeviance=7.421, d.f.=3, *P*=0.060). Although removing area from the full model resulted in a significantly worse fitting model, the full model was not significantly different from the null model (Δdeviance=8.181, d.f.=4, *P*=0.085).

Model 10:
Value of damage ~ distance from the MPNP + distance to the nearest field + (1|year/field ID)

Neither variable was significant, either alone (distance to nearest field model compared to null model Δdeviance=2.555, d.f.=1, *P*=0.110; distance from the MPNP model compared to null model Δdeviance=1.653, d.f.=1, *P*=0.199) or in combination (distance to nearest field removed from full model Δdeviance=1.953, d.f.=1, *P*=0.162; distance from the MPNP removed from full model Δdeviance=1.051, d.f.=1, *P*=0.305) at influencing the value of damage after a crop-foraging event.

Model 11:
Area of damage ~ boundary type + crop diversity + (1|year/field ID)

Neither variable was significant, either alone (crop diversity model compared to null model Δdeviance=3.048, d.f.=1, *P*=0.081; boundary model compared to null model Δdeviance=4.501, d.f.=2, *P*=0.105) or in combination (crop diversity removed from full model Δdeviance=3.269, d.f.=1, *P*=0.071; field boundary removed from full model Δdeviance=4.721, d.f.=2, *P*=0.094).

Model 13:
Area of damage ~ moon phase + month + (1|year/field ID)

The month did not significantly influence the area of damage, either by itself (month model compared to null model Δdeviance=4.855, d.f.=4, *P*=0.303), or in combination with moon phase (month removed from full model Δdeviance=9.115, d.f.=4, *P*=0.058). The removal of moon phase from the full model resulted in a significantly worse model (moon phase removed from full model Δdeviance=9.262, d.f.=3, *P*=0.026). However, it did not influence the area of damage alone (moon phase model compared to null model Δdeviance=5.002, d.f.=3, *P*=0.172). When controlling for month in the full model, no significant differences were observed in the area of damage between different moon phases.

Table S2.5. *P*-values for *post hoc* pairwise comparisons, comparing the value of damage (BWP) in a field for different moon phases after a crop-foraging event

Moon phase	New moon	Full moon	Waning	Waxing
New moon	-	-	-	-
Full moon	0.686	-	-	-
Waning	0.195	0.958	-	-
Waxing	0.053	0.887	0.995	-

Supplementary information 2

Table S3.1. Measurements for research sessions along different routes in the MPNP, Botswana (Figure 1.1)

Transect	Number of research sessions	Length of research session (hrs)	Distance travelled (km)
North	43	4.7 ± 0.2 (1.0-9.2)	59.1 ± 2.9 (13.0-124.0)
South	59	4.1 ± 0.1 (1.4-6.4)	53.9 ± 1.8 (17.0-73.0)
River	102	4.2 ± 0.1 (1.9-6.6)	42.4 ± 1.0 (14.0-75.0)
Njuca	37	3.3 ± 0.1 (1.1-5.5)	57.8 ± 2.5 (17.0-79.0)

Mean ± SE (range)

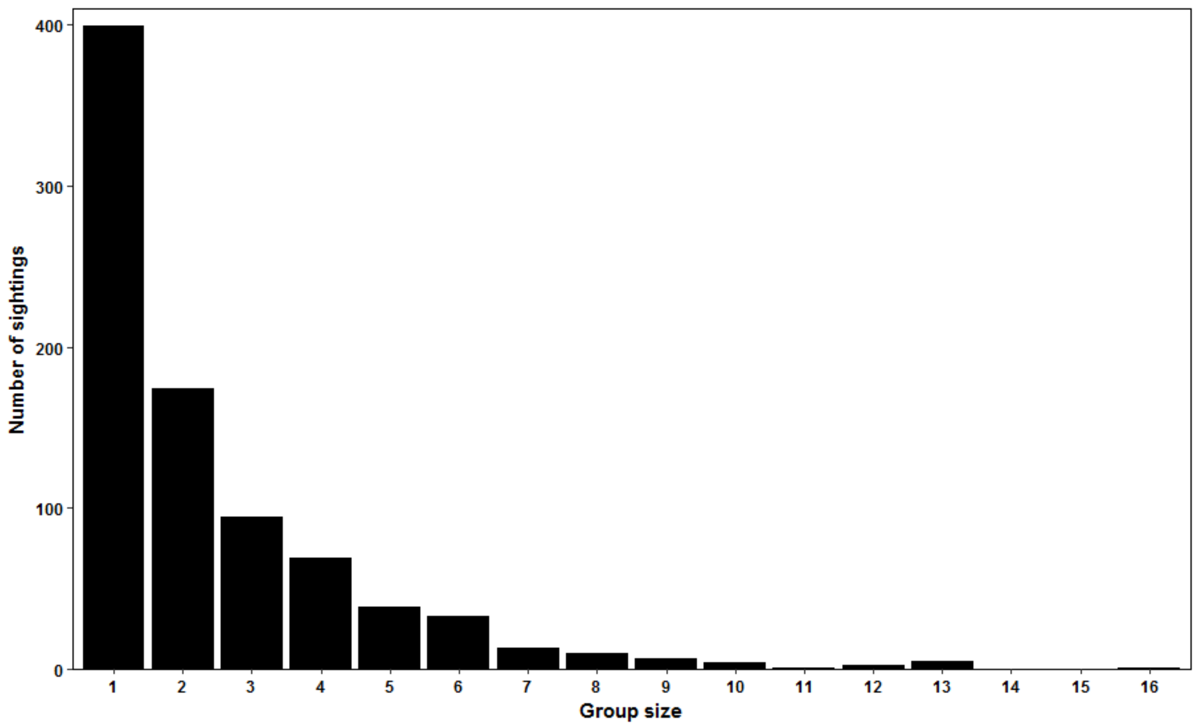

Figure S3.1. The number of male African elephant sightings categorised by group size with a confidence score of 1 and 2, observed inside the MPNP, Botswana, between January 2014 and July 2016 (n=853)

Table S3.2. *P*-values from Tukey tests comparing HFL measurements for different aged elephants. Significant *P*-values are shown in bold

Age	10-15	16-20	21-25	26-35	≥36
10-15	-	-	-	-	-
16-20	**0.007**	-	-	-	-
21-25	**<0.001**	**<0.001**	-	-	-
26-35	**<0.001**	**<0.001**	**<0.001**	-	-
≥36	**<0.001**	**<0.001**	**0.005**	0.999	-

Table S3.3. Predicted hind foot lengths for elephants based on their age

Age (yrs)	HFL (cm)
<10	<40.8
10-15	40.9 – 45.6
16-20	45.7 – 48.6
21-25	48.7 – 51.0
26-35	51.1 -54.1
≥36	>54.2

Table S3.4. The characteristics of movement trajectories recorded for African elephants in different crops when crop-foraging

Crop	Number of trajectories	Mean path length	Mean number of GPS locations
Cowpeas	22	45.5m ± 7.2 (7.2-130.3)	7.6 ± 1.3 (2.0-26.0)
Maize	18	60.5m ± 8.8 (8.7-159.9)	10.7 ± 1.5 (3.0-26.0)
Millet	25	63.2m ± 19.1 (5.8-430.5)	12.2 ± 3.4 (2.0-82.0)
Sorghum	12	50.7m ± 9.4 (18.3-130.8)	7.9 ± 1.2 (4.0-19.0)
Sweet reed	4	18.4m ± 8.3 (6.5-43.1)	4.8 ± 1.8 (2.0-10.0)
Watermelon	23	53.9m ± 8.5 (7.5-142.8)	12.9 ± 2.0 (2.0-35.0)

Mean ± SE (range)

Table S3.5. Tukey HSD *post hoc* pairwise comparisons for slopes of distance to the MPNP against group size of crop-foraging elephants between months. Significant *P*-values are shown in bold

Month	January	February	March	April	May
January	-	-	-	-	-
February	0.588	-	-	-	-
March	0.883	**<0.001**	-	-	-
April	1.000	0.084	0.742	-	-
May	1.000	0.706	0.866	0.998	-

Supplementary information 3

Questionnaire with attitude statements shown in both English and Setswana.

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Questionnaire

Farmer

Name: Sex: Male ☐ Female ☐

Age: <30 ☐ 31-40 ☐ 41-50 ☐ 51-60 ☐ 61-70 ☐ >70 ☐ UK ☐

Residency: <20yrs ☐ 21-40yrs ☐ 41-60yrs ☐ 61yrs ☐ UK ☐

Education:

Employed: Yes ☐ No ☐ If yes, employed as: ____________________

Ethnicity: ____________________

Occupation: Livestock ☐ Agriculture ☐ Both ☐

Use of field: Subsistence ☐ Commercial ☐ Both ☐

Number of dependents: ______________

Number of family members employed outside of farming: ______________

Poverty eradication scheme: Yes ☐ No ☐

Number of livestock species owned:

Cow: ___ Goat: ___ Donkey: ___ Horse: ___

Field

Number of fields owned: ______________ Date field was ploughed: ______________

Date seeds sown: ______________ Date finished in field: ______________

Crops grown: Maize ☐ Millet ☐ Sorghum ☐ Sweet reed ☐ Cowpeas ☐

Watermelon ☐ Pumpkin ☐ Lablab ☐ Butternuts ☐

Why do you grow these particular crops? Please select three:

Nutritional value ☐ Taste ☐ Commercial value ☐ Government provides seeds ☐

Fast growing ☐ Easy to harvest ☐ Can be stored ☐ Historically always have ☐

Other ☐

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Please rank crops in order of importance to you (1 being most important, 9 being least important):

Maize: ___ Millet: ___ Sorghum: ___ Sweet reed: ___ Cowpeas: ___ Watermelon: ___

Pumpkin: ___ Lablab: ___ Butternuts: ___

Please rank crops in order of preference to elephants (1 being most preferred, 9 being least preferred):

Maize: ___ Millet: ___ Sorghum: ___ Sweet reed: ___ Cowpeas: ___ Watermelon: ___

Pumpkin: ___ Lablab: ___ Butternuts: ___

Do you have defences in place to protect your field from elephants?: Yes ☐ No ☐

If yes, what defences do you have in place?:

Burn chilli ☐ Chilli fence ☐ Beehive fence ☐ Wire fence ☐ Scarecrow ☐

Banging drums ☐ Sleep in field ☐ Hanging material ☐ Other ☐

Was your field raided by elephants this year?: Yes ☐ No ☐

How many times were you raided?: _______

What percentage of the crop was destroyed?: _______

What would you value the damage to your crop at?: _______

What would you estimate the value of your field to be?: _______

On a scale of 1 to 5, how did this impact your family? (1 being minimum impact, 5 being large impact):

1 2 3 4 5

Has your field been raided by elephants in the last 5yrs?: Yes ☐ No ☐

Have you encountered elephants this year?: Yes ☐ No ☐

Have you encountered elephants in the last 5yrs?: Yes ☐ No ☐

Have you or a family member been directly injured by an elephant in the last 15yrs?:
Yes ☐ No ☐

On a scale of 1 to 5, how much do you know about elephants? (1 being, I know nothing about elephants, 5 being, I am very knowledgeable about elephants):

1 2 3 4 5

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Value Statements

1) Elephants are important because the presence of elephants is a sign of a healthy environment.

Strongly Disagree — Disagree — Neutral — Agree — Strongly Agree

2) Elephants are important because protecting elephants means that other wildlife and habitats are protected.

Strongly Disagree — Disagree — Neutral — Agree — Strongly Agree

3) I enjoy seeing elephants in the national park.

Strongly Disagree — Disagree — Neutral — Agree — Strongly Agree

4) I would like to learn more about elephant biology, behaviour and ecology.

Strongly Disagree — Disagree — Neutral — Agree — Strongly Agree

5) I would support research on human-elephant conflict.

Strongly Disagree — Disagree — Neutral — Agree — Strongly Agree

6) Elephants are important because they represent power and intelligence.

Strongly Disagree — Disagree — Neutral — Agree — Strongly Agree

7) Elephants are a national treasure.

Strongly Disagree — Disagree — Neutral — Agree — Strongly Agree

8) Elephants have a right to exist in their natural habitat.

Strongly Disagree — Disagree — Neutral — Agree — Strongly Agree

9) Elephants attract tourists which bring revenue to the park which provides incentives to the community.

Strongly Disagree — Disagree — Neutral — Agree — Strongly Agree

10) Elephants deserve protection.

Strongly Disagree — Disagree — Neutral — Agree — Strongly Agree

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Tolerance Statements

1) People do not get angry at all even if elephants often raid fields.

Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree

2) People get angry and may kill an elephant if it raids their field often.

Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree

3) People do not get angry at all even if elephants threaten them.

Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree

4) People get angry and may kill an elephant if it threatens them.

Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree

5) If people receive compensation for elephant crop damage they do not get angry.

Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree

6) If people receive compensation for elephant crop damage they still get angry and may kill an elephant.

Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree

7) If the compensation system was improved (faster and more compensation) people would not get angry when elephants raid fields.

Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree

8) If the compensation system was improved (faster and more compensation) people would still get angry and may kill an elephant.

Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree

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Value Statements

1) Ditlou dimosala ka gore boleteng ja ditlou ke sekai sa tikologo ee itekanetseng.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

2) Ditlou dimosala ka gore go di somarela goraa gore phologolo tse dingwe le matoto a tholego a somarelegile.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

3) Ke rata go bona ditlou mo lefelong la diphologolo.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

4) Ke ta rata go ithuta ka botshelo ja tlou, go thaloganya boitshwaro jwa tsune le gore e tshela jang le diphologolo tse di-ngwe.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

5) Ke taa rotoetsa dipatisiso tse di lebang e bile di rarabolola kgothang magareng ga batho le ditlou.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

6) Ditlou di mosola ka di supa marapo le bothale.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

7) Ditlou ke matoto a sechaba.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

8) Ditlou dina le tshwarelo ya go tshela mo tikologong ya tsone ya tholego.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

9) Ditlou di tisa bajanala ba tisang madi mo lefelong la diphologolo mme meamuso e akolwa ke setshaba.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

10) Ditlou dithoka go somarelwa.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Tolerance Statements

1) Batho ga ba utlwe bothoko le e seng fa ditlou dija masimo a bone ka nako dingwe.

Gake dumelane gothelele	Gake dumele	Ke fa gore	Ke a dumela	Ke demelana thata

2) Batho ba a galega thata mme e bile baka tsaa tshwetso ya go bolaa tlou nako dingwe fa e le gore tlou enna e ba jela dijalo kgapetsa.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

3) Batho ga ba galefe gothelele fa ditlou di ba tshosetsa motshelo.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

4) Batho ba ka galefa mme e bile bafelele ba bolaa tlou fa e le gore tlou ya gonna jalo e ba tshosetsa matshelo.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

5) Fa batho ba amogela phimolo dikeledi morago ga tshenyo ya ditou mo masimo ga ba galefe.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

6) Fa batho a bone phimolo dikeledi morago ga tshenyo ya ditlou bantse ba a galefa mme e bile monakong dingwe baka bolaa tlou.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

7) Phimolo dikeledi morago ga tshenyo ya ditou fa e ka thabololwa ya irwa bonako go thusa batswa sethabelo le dikatso tsa phimolo dikeledi tsaa fa godimo batho ga ba kita ba galega morago ga tshenyo ya ditou mo masimong.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

8) Phimolo dikeledi morago ga tshenyo ya ditou lefa eka thabololwa ya irwa bonako go thusa batswa sethabelo le dikatso tsaya fa godimo batho bantse batile go galega morago ga tshenyo ya ditou mo masimong mme ebile ba bangwe baka felela ba bolaa ditou/tlou.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Questionnaire breakdown

Characteristics of farmer: The sex of the farmer was recorded. Their age was categorized into seven ordinal groups (<30 years, 31-40 years, 41-50 years, 51-60 years, 61-70 years, >70 years and unknown). The village the farmer resided in was recorded and the length of residency categorized into five ordinal groups (<20 years, 21-40 years, 41-60 years, >61 years and unknown). The highest stage of education completed was categorized into six ordinal groups (none, crèche, primary, junior secondary, senior secondary and tertiary). Ethnicity was recorded. The current employment status of the farmer was recorded and whether they were involved in livestock production, agriculture or both. The farmer was asked whether they used their field for commercial purposes, subsistence or both. The number of dependants was recorded as well as the number of family members employed outside of farming. Farmers were asked whether they were enrolled on the Government Poverty Eradication Scheme Ipelegeng. Ipelegeng is a government-funded programme that provides short-term employment support for community members to complete development projects within their community if eligible. Finally, a wealth score was allocated to the farmer based on the number of livestock owned by converting the number of cows, goats, donkeys and horses into Livestock Standard Units (LSU), using the following conversion factors: 1 cow = 0.7 LSU, 1 donkey = 0.5 LSU, 1 goat = 0.1 LSU and 1 horse = 0.8 LSU (tropical livestock units).

Characteristics of field and farming practices: The number of fields owned by the farmer was recorded, as well as the date of ploughing, sowing seeds and when they had completed harvest. Based on the date provided by the farmer, the number of days that had passed since the first of August 2014 (when the first farmer ploughed their field) was calculated to score when farmers ploughed, sowed the seeds and finished in their field. The month the farmer completed each activity was extracted and stored. Farmers selected which crops they grew and why they grew these crops. Farmers ranked a list of crops from one to nine in order of importance for both themselves and which crops they thought elephants preferred.

Crop-foraging events and experience with elephants: Farmers were asked whether elephants had entered their field that year. If so, they were asked how many times they entered, what percentage of their crop was damaged and what value they placed on the damage. Farmers were also asked to estimate the value of all the crops in their field. How the crop-foraging events affected the farmer's family was recorded on a five-point scale, one being a minimum, and five large, impact. If elephants had not entered their field that year, the farmers were asked whether elephants had entered their fields in the last five years. They were also asked whether they had encountered elephants that year and, if they had not, whether they had encountered elephants in the last five years. Farmers were asked whether they or a family member had been directly injured by an elephant in the last 15 years. Finally, they were asked how much they knew about elephants. They selected an answer from a five-point scale, one being, "I know nothing about elephants", five being "I am very knowledgeable about elephants".

Table S4.1. Statistical tests used to determine which factors influence attitude scores of farmers in the Makgadikgadi region

Farmer characteristics	Statistical test	
	Value	Tolerance
Sex	Mann-Whitney U	Mann-Whitney U
Age	Kruskal-Wallis	Kruskal-Wallis
Adjusted age	Mann-Whitney U	Mann-Whitney U
Ethnicity	Kruskal-Wallis	Kruskal-Wallis
Community	Mann-Whitney U	Mann-Whitney U
Residency	Kruskal-Wallis	Kruskal-Wallis
Adjusted residency	Mann-Whitney U	Mann-Whitney U
Education	Kruskal-Wallis	Kruskal-Wallis
Adjusted education	Mann-Whitney U	Mann-Whitney U
Employment status	Mann-Whitney U	Mann-Whitney U
Number of dependants	Spearman’s rank-order correlation	Spearman’s rank-order correlation
Number of family employed	Spearman’s rank-order correlation	Spearman’s rank-order correlation
Wealth	Spearman’s rank-order correlation	Spearman’s rank-order correlation
Crop-foraging events and experiences with elephants		
Elephants entered field that year	Mann-Whitney U	Mann-Whitney U
Number of times field entered	Spearman’s rank-order correlation	Spearman’s rank-order correlation
Perceived % damage	Spearman’s rank-order correlation	Spearman’s rank-order correlation
Perceived value of damage	Spearman’s rank-order correlation	Spearman’s rank-order correlation
Impact	Kruskal-Wallis	Kruskal-Wallis
Encountered elephants in the last year	Mann-Whitney U	Mann-Whitney U
Perceived knowledge of elephants	Kruskal-Wallis	Kruskal-Wallis

Table S4.2. Summary of farmers characteristics in the Makgadikgadi region, Botswana (n=143)

Farmer characteristics	Categories	N (%)	Adjusted	N (%)
Sex	Male	40 (28%)		
	Female	103 (72.0%)		
Age (years)	<30	2 (1.4%)	<50	45 (31.5%)
	31-40	18 (12.6%)	>51	98 (68.5%)
	41-50	25 (17.5%)		
	51-60	39 (27.3%)		
	61-70	29 (20.3%)		
	>70	21 (14.7%)		
	Unknown	9 (6.3%)		
Community	Khumaga	99 (69.2%)		
	Moreomaoto	44 (30.8%)		
Residency (years)	<20	13 (9.1%)	<40	37 (27.4%)
	21-40	24 (16.8%)	>41	98 (72.6%)
	41-60	57 (39.9%)		
	>60	41 (28.7%)		
	Unknown	8 (5.6%)		
Ethnicity	Moyeyi	46 (32.2%)		
	Monajwa	34 (23.8%)		
	Mosarwa	4 (2.8%)		
	Mosobea	10 (7.0%)		
	Mokalanga	36 (25.2%)		
	Morotsi	5 (3.5%)		
	Mokgalagadi	6 (4.2%)		
	Mokgatla	1 (0.7%)		
	Mohurutshe	1 (0.7%)		
Education	None	57 (40.1%)	None	57 (40.1%)
	Creche	6 (4.2%)	Education	85 (59.9%)
	Primary	61 (43.0%)		
	Junior secondary	13 (9.2%)		
	Senior secondary	4 (2.8%)		
	Tertiary	1 (0.7%)		
Employed	Yes	9 (6.3%)		
	No	134 (93.7%)		
Occupation	Agriculture	30 (21.0%)		
	Agriculture and livestock	113 (79.0%)		
Use of field	Subsistence	59 (41.3%)		
	Commercial	1 (0.7%)		
	Both	83 (58.0%)		
Poverty eradication scheme	Yes	47 (32.9%)		
	No	96 (67.1%)		

	Mean
Number of dependants	8 (range 1-32, SD 5.3)
Number of family employed	0.9 (range 0-5, SD 1.1)

Table S4.3. Summary of field characteristics in the Makgadikgadi region, Botswana

Field characteristics	Mean	
Fields owned	1.4 (range 1-4, SD 0.5)	
Number of crop species	5.4 (range 1-9, SD 1.5)	
	Categories	N (%)
Farmers growing crop	Maize	141 (98.6%)
	Cowpeas	135 (94.4%)
	Watermelons	131 (91.6%)
	Sorghum	98 (68.5%)
	Millet	90 (62.9%)
	Sweet reed	89 (62.2%)
	Pumpkin	63 (44.1%)
	Butternuts	17 (11.9%)
	Lablab	3 (2.1%)
Defence in place	Yes	120 (83.9%)
	No	23 (16.1%)

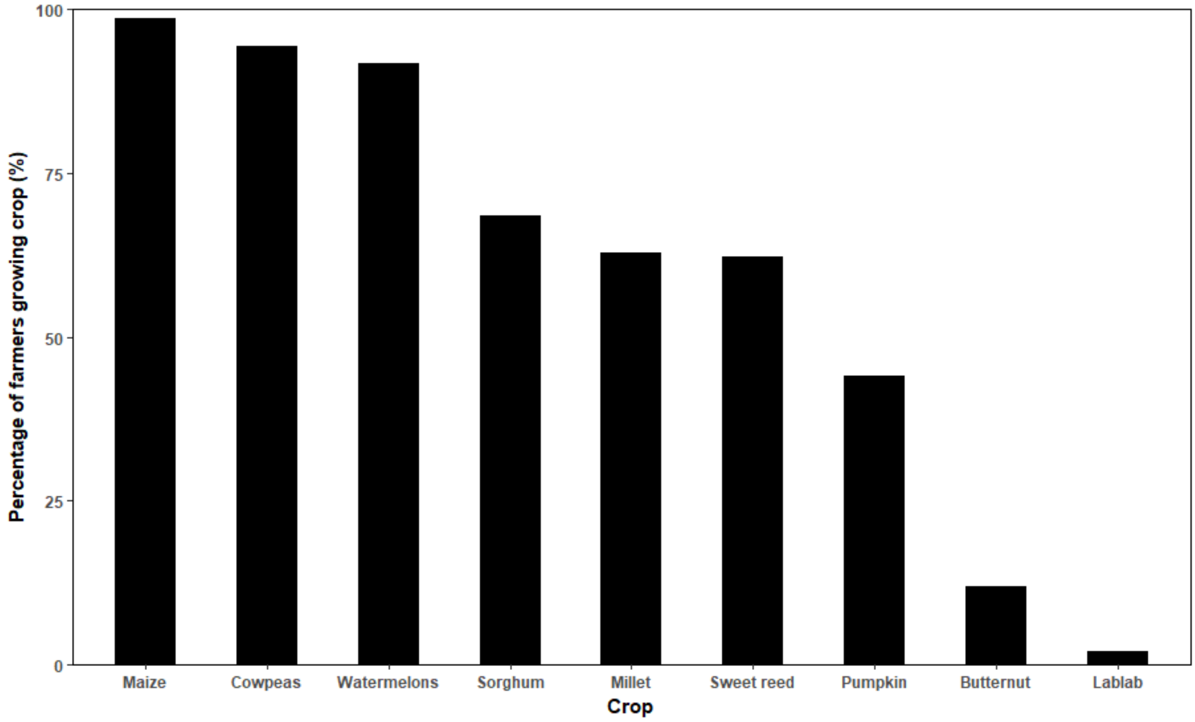


Figure S4.1. The percentage of farmers growing each crop species in the Makgadikgadi region in 2014, as reported by the farmer

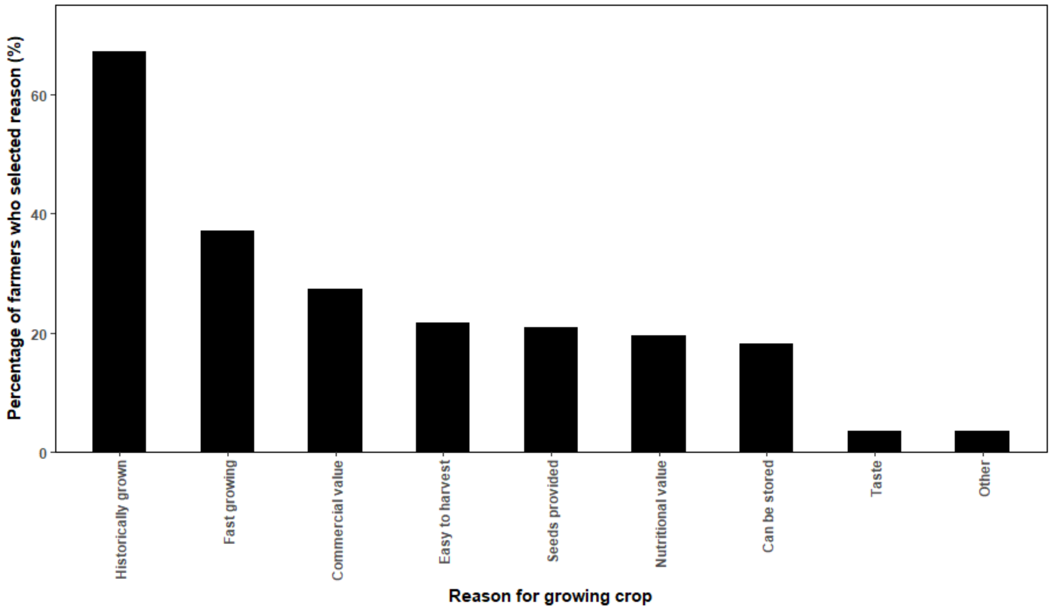


Figure S4.2. The percentage of farmers that selected reasons for growing certain crop species

Table S4.4. Summary of crop-foraging events and experiences with elephants

Crop-foraging events and experiences with elephants	Categories	N (%)
Elephants entered this year	Yes	119 (83.2%)
	No	24 (16.8%)
Elephants entered in the last 5 years	Yes	129 (90.2%)
	No	11 (7.7%)
	Unknown	3 (2.1%)
Encountered elephants this year	Yes	132 (92.3%)
	No	11 (7.7%)
Encountered elephants in the last 5 years	Yes	134 (93.7%)
	No	7 (4.9%)
	Unknown	2 (1.4%)
Family member injured by an elephant	Yes	0 (0.0%)
	No	143 (100.0%)
Impact of crop-foraging event	1 (minimum)	0 (0.0%)
	2	0 (0.0%)
	3	7 (6.0%)
	4	10 (8.6%)
	5 (large)	100 (85.5%)
Perceived knowledge of elephants	1 (I know nothing)	54 (37.8%)
	2	3 (2.1%)
	3	15 (10.5%)
	4	4 (2.8%)
	5 (I am very knowledgeable)	67 (46.9%)

	Mean
Number of times field entered	3.4 (range 1-15, SD 2.5)
Perceived % damage	82.9% (range 0-100, SD 27.7)
Perceived value of damage	BWP 11,587 (range 0-200,000, SD 24,811.1)

Table S4.5. Summary of responses to attitude statements

Value statement	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Elephants are important because the presence of elephants is a sign of a healthy environment.	9 (6.3%)	68 (47.6%)	15 (10.5%)	46 (32.2%)	5 (3.5%)
Elephants are important because protecting elephants means that other wildlife and habitats are protected.	12 (8.4%)	51 (35.7%)	11 (7.7%)	56 (39.2%)	13 (9.1%)
I enjoy seeing elephants in the national park.	1 (0.7%)	24 (16.8%)	1 (0.7%)	102 (71.3%)	15 (10.5%)
I would like to learn more about elephant biology, behaviour and ecology.	5 (3.5%)	56 (39.2%)	3 (2.1%)	61 (42.7%)	18 (12.6%)
I would support research on human-elephant conflict.	1 (0.7%)	24 (16.8%)	8 (5.6%)	89 (62.2%)	21 (14.7%)
Elephants are important because they represent power and intelligence.	2 (1.4%)	60 (42.0%)	10 (7.0%)	63 (44.1%)	8 (5.6%)
Elephants are a national treasure.	1 (0.7%)	29 (20.3%)	8 (5.6%)	91 (63.6%)	14 (9.8%)
Elephants have a right to exist in their natural habitat.	2 (1.4%)	17 (11.9%)	6 (4.2%)	102 (71.3%)	16 (11.2%)
Elephants attract tourists which bring revenue to the park which provides incentives to the community.	4 (2.8%)	34 (23.8%)	8 (5.6%)	78 (54.6%)	19 (13.3%)
Elephants deserve protection.	0 (0.0%)	30 (21.0%)	7 (4.9%)	96 (67.1%)	10 (7.0%)

Table S4.6. Summary of responses to tolerance statements

Tolerance statement	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
People do not get angry at all even if elephants often raid fields.	15 (10.5%)	106 (74.1%)	5 (3.5%)	13 (9.1%)	4 (2.8%)
People get angry and may kill an elephant if it raids their field often.	2 (1.4%)	13 (9.1%)	1 (0.7%)	113 (79.0%)	14 (9.8%)
People do not get angry at all even if elephants threaten them.	10 (7.0%)	108 (75.5%)	4 (2.8%)	19 (13.3%)	2 (1.4%)
People get angry and may kill an elephant if it threatens them.	2 (1.4%)	13 (9.1%)	3 (2.1%)	114 (79.7%)	11 (7.7%)
If people receive compensation for elephant crop damage they do not get angry.	2 (1.4%)	62 (43.4%)	3 (2.1%)	71 (49.7%)	5 (3.5%)
If people receive compensation for elephant crop damage they still get angry and may kill an elephant.	2 (1.4%)	33 (23.1%)	5 (3.5%)	94 (65.7%)	9 (6.3%)
If the compensation system was improved (faster and more compensation) people would not get angry when elephants raid fields.	1 (0.7%)	44 (30.8%)	4 (2.8%)	81 (56.6%)	13 (9.1%)
If the compensation system was improved (faster and more compensation) people would still get angry and may kill an elephant.	2 (1.4%)	36 (25.2%)	11 (7.7%)	83 (58.0%)	11 (7.7%)

Table S4.7. The effects of farmer characteristics on value for, and tolerance towards, African elephants. Highlighted boxes with bold text indicate factors that significantly influenced value and tolerance

Farmer characteristics	Statistics	
	Value	Tolerance
Sex	Mann-Whitney U: $W_{40,103}$=1706.0, P=0.111	Mann-Whitney U: $W_{40,103}$=2120.5, P=0.786
Age	Kruskal-Wallis: χ^2=7.487, d.f.=6, P=0.278	Kruskal-Wallis: χ^2=1.507, d.f.=5, P=0.912
Adjusted age	Mann-Whitney U: $W_{45,98}$=1855.5, P=0.128	Mann-Whitney U: $W_{45,98}$=2228.0, P=0.922
Ethnicity	Kruskal-Wallis: χ^2=8.725, d.f.=8, P=0.366	Kruskal-Wallis: χ^2=1.599, d.f.=8, P=0.991
Community	**Mann-Whitney U: $W_{99,44}$=1390.5, P<0.001**	Mann-Whitney U: $W_{99,44}$=1863.5, P=0.167
Residency	Kruskal-Wallis: χ^2=1.009, d.f.=3, P=0.799	Kruskal-Wallis: χ^2=0.606, d.f.=3, P=0.895
Adjusted residency	Mann-Whitney U: $W_{37,98}$=1943.5, P=0.521	Mann-Whitney U: $W_{37,98}$=1963.0, P=0.458
Education	Kruskal-Wallis χ^2=2.083, d.f.=5, P=0.838	Kruskal-Wallis: χ^2=5.767, d.f.=5, P=0.329
Adjusted education	Mann-Whitney U: $W_{57,85}$=2250.0, P=0.473	Mann-Whitney U: $W_{57,85}$=2546.0, P=0.606
Employment status	Mann-Whitney U: $W_{134,9}$=482.0, P=0.316	Mann-Whitney U: $W_{134,9}$=696.5, P=0.436
Number of dependants	Spearman's rank-order correlation: r_s= 0.025, d.f.=141, P=0.764	Spearman's rank-order correlation: r_s=-0.062, d.f.=141, P=0.464
Number of family employed	Spearman's rank-order correlation: r_s= -0.068, d.f.=141, P=0.420	Spearman's rank-order correlation: r_s=-0.121, d.f.=141, P=0.150
Wealth	Spearman's rank-order correlation: r_s=-0.081, d.f.=141, P=0.339	Spearman's rank-order correlation: r_s=-0.048, d.f.=141, P=0.570

Table S4.8. The effects of crop-foraging events and experiences with elephants on value for, and tolerance towards, African elephants. Highlighted boxes with bold text indicate factors that significantly influenced value and tolerance

Crop-foraging events and experiences with elephants	Statistics	
	Value	Tolerance
Elephants entered field that year	**Mann-Whitney U: $W_{119,24}$=1845.0, *P*=0.024**	**Mann-Whitney U: $W_{119,24}$=1957.5, *P*=0.004**
Number of times field entered	Spearman's rank-order correlation: r_s= -0.189, d.f.=94, *P*=0.065	**Spearman's rank-order correlation: r_s=-0.204, d.f.=94, *P*=0.047**
Perceived % damage	Spearman's rank-order correlation: r_s= 0.127, d.f.=116, *P*=0.170	Spearman's rank-order correlation: r_s=0.007, d.f.=115, *P*=0.937
Perceived value of damage	Spearman's rank-order correlation: r_s= 0.077, d.f.=115, *P*=0.410	Spearman's rank-order correlation: r_s=-0.005, d.f.=115, *P*=0.958
Impact	Kruskal-Wallis: χ^2=0.047, d.f.=2, *P*=0.977	Kruskal-Wallis: χ^2=0.145, d.f.=2, *P*=0.929
Encountered elephants in the last year	**Mann-Whitney U: $W_{11,132}$=1031.5, *P*=0.021**	Mann-Whitney U: $W_{11,132}$=961.0, *P*=0.074
Perceived knowledge of elephants	Kruskal-Wallis: χ^2=0.739, d.f.=4, *P*=0.946	Kruskal-Wallis: χ^2=1.862, d.f.=4, *P*=0.761

Table S4.9. The effect of farming practice timing on crop-foraging events

	Farming practice						
	Ploughing field		Sowing seeds		Finishing in field		Days between sowing and finishing
	Month	Days	Month	Days	Month	Days	Days
Number of crop-foraging events	Kruskal-Wallis: χ^2=4.040, d.f.=5, P=0.544	Spearman's rank-order correlation: r_s=-0.203, d.f.=88, P=0.055	Kruskal-Wallis: χ^2=4.160, d.f.=5, P=0.526	Spearman's rank-order correlation: r_s=-0.183, d.f.=88, P=0.085	Kruskal-Wallis: χ^2=4.495, d.f.=7, P=0.721	Spearman's rank-order correlation: r_s=-0.034, d.f.=86, P=0.755	Spearman's rank-order correlation: r_s=0.103, d.f.=86, P=0.341
Perceived percentage damage	Kruskal-Wallis: χ^2=6.18, d.f.=6, P=0.403	Spearman's rank-order correlation: r_s=-0.102, d.f.=115, P=0.273	Kruskal-Wallis: χ^2=6.13, d.f.=6, P=0.409	Spearman's rank-order correlation: r_s=-0.097, d.f.=115, P=0.298	Kruskal-Wallis: χ^2=4.516, d.f.=7, P=0.719	Spearman's rank-order correlation: r_s=-0.042, d.f.=113, P=0.656	Spearman's rank-order correlation: r_s= 0.027, d.f.=113, P=0.777
Perceived value of damage	Kruskal-Wallis: χ^2=11.850, d.f.=6, P=0.065	Spearman's rank-order correlation: r_s=-0.096, d.f.=111, P=0.312	Kruskal-Wallis: χ^2=9.546, d.f.=6, P=0.145	Spearman's rank-order correlation: r_s=-0.081, d.f.=111, P=0.397	Kruskal-Wallis: χ^2=4.225, d.f.=7, P=0.754	Spearman's rank-order correlation: r_s=-0.121, d.f.=109, P=0.206	Spearman's rank-order correlation: r_s=-0.056, d.f.=109, P=0.559

Table S4.10. *Post hoc* pairwise comparisons using Tukey and Kramer (Nemenyi) test with Tukey-Dist approximation of farmers' importance for different crops. Significant *P*-values are shown in bold

Crop	Cowpeas	Butternut	Lablab	Maize	Millet	Pumpkin	Sorghum	Sweet reed	Watermelon
Cowpeas	-	-	-	-	-	-	-	-	-
Butternut	**<0.001**	-	-	-	-	-	-	-	-
Lablab	**<0.001**	**<0.001**	-	-	-	-	-	-	-
Maize	0.154	**<0.001**	**<0.001**	-	-	-	-	-	-
Millet	0.252	**<0.001**	**<0.001**	1	-	-	-	-	-
Pumpkin	**<0.001**	**0.009**	**<0.001**	**<0.001**	**<0.001**	-	-	-	-
Sorghum	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.766	-	-	-
Sweet reed	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.986	0.999	-	-
Watermelon	**0.034**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.081	0.941	0.592	-

Table S4.11. *Post hoc* pairwise comparisons using Tukey and Kramer (Nemenyi) test with Tukey-Dist approximation of farmers' perceptions of elephant preferences for different crops. Significant *P*-values are shown in bold

Crop	Cowpeas	Butternut	Lablab	Maize	Millet	Pumpkin	Sorghum	Sweet reed	Watermelon
Cowpeas	-	-	-	-	-	-	-	-	-
Butternut	**<0.001**	-	-	-	-	-	-	-	-
Lablab	**<0.001**	**0.036**	-	-	-	-	-	-	-
Maize	**<0.001**	0.999	**0.006**	-	-	-	-	-	-
Millet	**0.006**	**<0.001**	**<0.001**	**<0.001**	-	-	-	-	-
Pumpkin	**<0.001**	0.411	**<0.001**	0.769	**0.001**	-	-	-	-
Sorghum	**0.009**	**<0.001**	**<0.001**	**<0.001**	1	**<0.001**	-	-	-
Sweet reed	0.921	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	-	-
Watermelon	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.020**	-

Supplementary information 4

Example calculations for estimates of damage using different compensation techniques

Field details:

1ha of ploughed area
Crops present: Maize, beans, millet and watermelons

Farmers' perceived value of damage

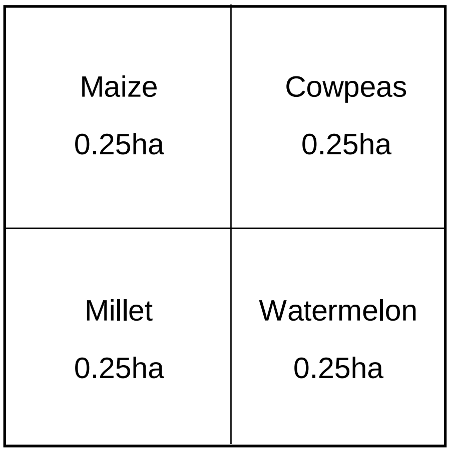
Crop	No. of units	Unit	Price per unit (BWP)	Total (BWP)
Maize	3	50kg	340	1020
Cowpeas	1	50kg	700	700
Millet	2	50kg	400	800
Watermelons	1	load	600	600
			Total	3120

Estimated value of crop=BWP 3120

Estimated % of damage=50%

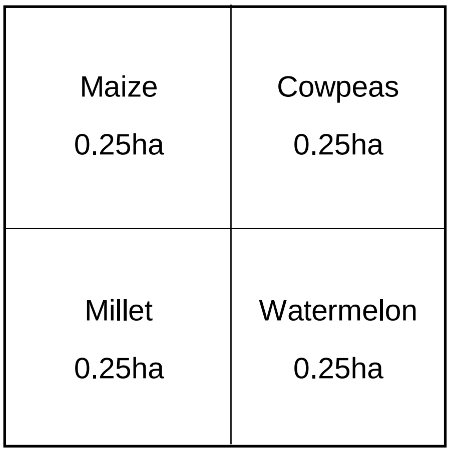
Estimate value of damage=BWP 1560

PAC value of damage



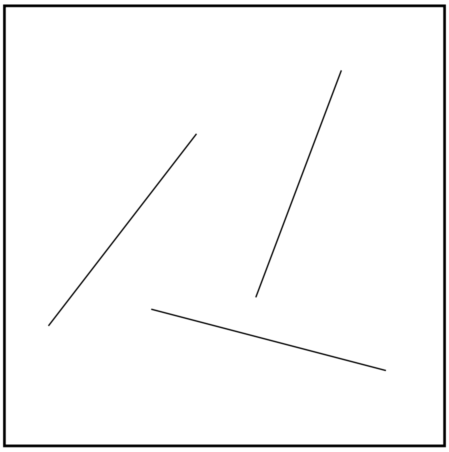
Crop	Area (ha)	Price/ha (BWP	Total (BWP)
Maize	0.25	900	225
Cowpeas	0.25	2500	625
Millet	0.25	700	175
Watermelons	0.25	0	0
		Total	1025

PAC value of damage using PAC approach including uncompensated crops



Crop	Area (ha)	Price/ha (BWP)	Total (BWP)
Maize	0.25	900	225
Cowpeas	0.25	2500	625
Millet	0.25	700	175
Watermelons	0.25	16000	4000
		Total	5025

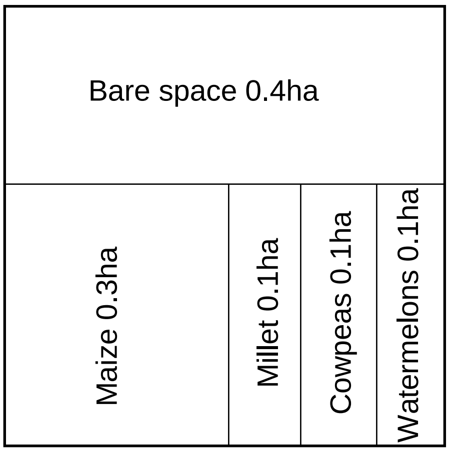
Transect value of damage



Crop	Paces of damage	Area (ha)	Price/ha (BWP)	Total (BWP)
Maize	62	0.14	900	126
Cowpeas	31	0.07	2500	175
Millet	22	0.05	700	35
Watermelons	40	0.09	16000	1440
			Total	1776

Percentage damage = 58.5% of crops damaged

Transect value of damage if 100% damage to crop



Crop	Paces of crop	Area (ha)	Price/ha (BWP)	Total (BWP)
Maize	133	0.3	900	270
Cowpeas	44	0.1	2500	250
Millet	44	0.1	700	70
Watermelons	44	0.1	16000	1600
			Total	2190

Transect value of damage if 100% damage to crop and no bare space

Crop	**Crop composition**	**Area (ha)**	**Price/ha (BWP)**	**Total (BWP)**
Maize	50%	0.5	900	450
Cowpeas	16%	0.16	2500	400
Millet	16%	0.16	700	112
Watermelons	16%	0.16	16000	2560
			Total	3522

Table S5.1. *P*-values for *post hoc* pairwise comparisons using paired t-test (P-value adjusted using Bonferroni method), comparing estimates of damage for different techniques: 1) farmers', 2) PAC, 3) PAC including watermelons, 4) transect method, 5) transect method assuming 100% damage, and 6) transect method assuming 100% damage and no bare space. Significant *P*-values are shown in bold

Compensation technique	1	2	3	4	5	6
1	-	-	-	-	-	-
2	**<0.001**	-	-	-	-	-
3	1	**<0.001**	-	-	-	-
4	**<0.001**	**<0.001**	**<0.001**	-	-	-
5	**<0.001**	1	**<0.001**	**<0.001**	-	-
6	0.200	**0.04**	0.180	**<0.001**	**<0.001**	-

Table S5.2. *P*-values for *post hoc* pairwise comparisons using pairwise sign test, comparing the percentage difference between predicted and actual income for different scenarios: 1) standard, 2) adjust predicted income for average crop values, 3) adjust for uncompensated crops, and 4) adjust for percentage damage scenarios. Significant *P*-values are shown in bold

Scenario	1	2	3	4
1	-	-	-	-
2	0.728	-	-	-
3	**<0.001**	**0.001**	-	-
4	**0.012**	**<0.001**	0.215	-